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of the

American Welding Society

December, 1929

Published Monthly
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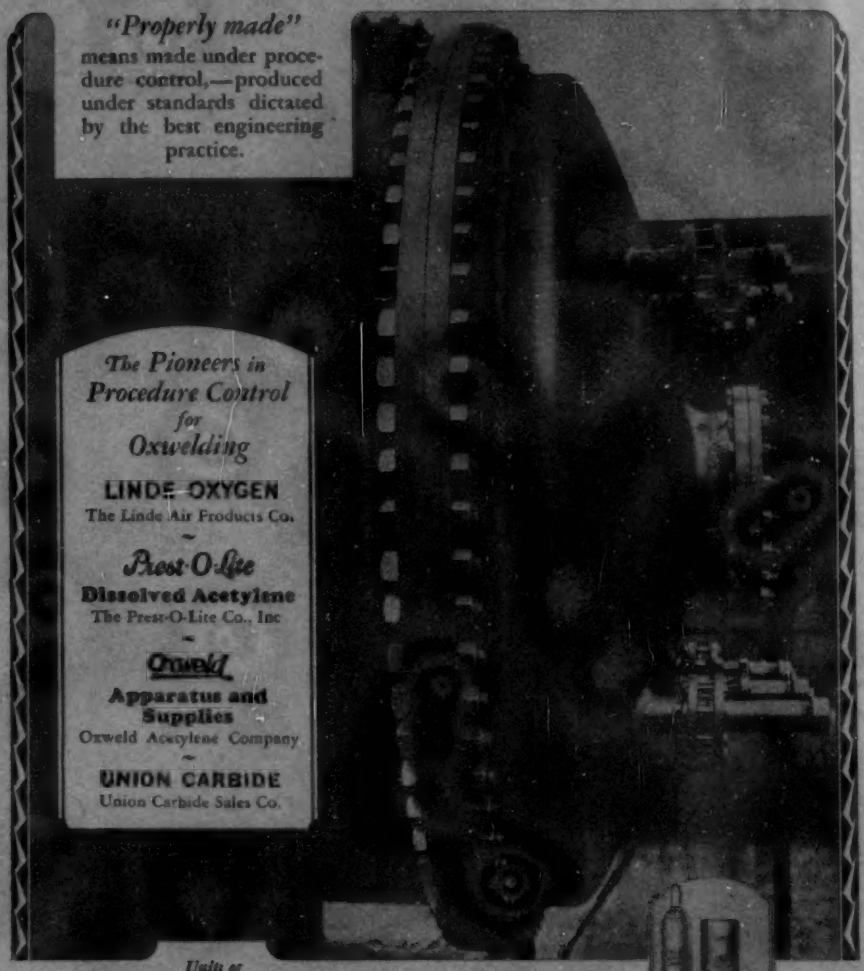

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JOURNAL

of the

AMERICAN WELDING SOCIETY

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AMERICAN WELDING SOCIETY
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JOURNAL

Volume 7 December, 1929 Number 12

Our Membership Campaign

There is printed elsewhere in this Journal an editorial taken from *The Welding Engineer* entitled "Get Your Man" which merits the consideration of every member of the Society.

The welding industry was never in better condition that it is at the present. Engineers are better informed as to facts concerning welding and there is less and less inclination on their part to place unjust restrictions against welding. Through the American Welding Society cooperation has been secured among the leaders in the welding field. Companies representing competitive processes have united in working for the constructive advancement of the industry.

The American Welding Society acts as a source of dependable information and through its research department, American Bureau of Welding, which is closely identified with the Division of Engineering of the National Research Council, technical problems confronting the industry are successfully solved through cooperative effort.

It is through such organized cooperation that the industry will advance, technical problems will be solved and codes and standards will be promulgated which will have an authoritative standing. The individual concern, no matter how large, is unable to cope successfully with these problems.

The American Welding Society is the common spokesman for the welding industry in such matters and deserves the cooperation of every one identified with it.

We trust that every member will seriously consider the request of the Membership Committee, that each member of the Society constitute himself as a Committee of One, to secure one new member. There is given elsewhere in this issue a list of the new members and proposers for the period of Nov. 15 to Dec. 15. A similar list for the period Oct. 15 to Nov. 15 was published in the previous issue of the Journal. The "member for member campaign" ends Feb. 1, 1930. At that time a complete list of those members who have secured at least one new member will be published. The American Welding Society occupies a strong position and with the addition of the new members secured in this campaign it will be equipped to extend its influence and work for the benefit of all concerned.

Get Your Man

Reprinted from November, 1929, issue of The Welding Engineer

For an entire season the football team of a mid-western college several years ago was undefeated as the result of the persistent thinking of a brilliant young quarterback who started every play with the signal, "Get Your Man!" This unceasing admonition to his ten husky playmates, that each man on the team was expected to do his bit, made it possible to keep going ahead against all kinds of opposition. Something of this spirit should be acquired by members of the American Welding Society in support of the plan recently proposed by the Membership Committee to put on a member-for-member campaign during the remainder of the year. Every member of the American Welding Society will receive with his copy of the JOURNAL OF THE AMERICAN WELDING SOCIETY this month a letter from the Chairman of the National Membership Committee outlining the purpose of this membership drive and urging each member to add at least one name to the enrollment. If the Society already had a very high coverage of all the industries which are using the welding processes it might be too much to expect a response from every present member. The fact is that the Society

does not have much coverage at present. There are thousands of men who can profit by membership and the greater increase which is made in the membership during the next year the more the organization will be able to do for welding executives individually and collectively. It does not seem possible that any member should have to look very far to find among his acquaintances one man who does not belong and who should belong to the American Welding Society. To get that man enrolled is to do something for the new members, something for the whole Society, and, last, but not least, something for himself. This move toward getting more members is not a fund-raising campaign. The Treasurer's report shows the finances of the Society to be in excellent condition although there are things which it can do to very good advantage with any additional income which might be derived from doubling its membership. The important thing from the point of view of the whole Society and of each individual member is that the work which the American Welding Society is doing is worthy of considerably more talent. It should be a very attractive proposition for industrial executives who are giving more and more consideration to welding to pool their experiences, their activities and their knowledge with others who are doing similar work and to gain what they can from this consolidated effort to extend and improve welding practice.

Carnegie Tech. Has Large Welding School

(From a News Release)

The Carnegie Institute of Technology now has the largest school for the training of welders of any college in the United States.

The classes at Carnegie consist of two groups, one to teach skill in welding considering the torch and electrode as tools, and the other to teach the young engineer the possibilities of welding in his chosen profession.

The night classes in welding have an enrollment of over 250 students. These are selected from a long list of applicants from the various metal trades in Pittsburgh. The night instruction is conducted to perfect skill and to give some ideas of the reasons for fusion of metals, penetration, expansion and contraction, etc. The day classes have an enrollment of over 350 and special attention is given to structural, aeronautical, automotive, pipe and container welding.

Arc welding is done in separate booths, each containing a control panel, a rheostat, a reactor, a work table, a head shield, and electrode holder and accessories. Welding current is furnished by a 1000 ampere and two portable single-operator sets.

Gas welding is carried on with 16 modern torches conveniently piped from gas manifolds. Work tables, preheat muffles and accessories are available for each welder.

To keep abreast of the times, Prof. S. E. Dibble, head of the department in which the welding instruction is given, has been instrumental in enlarging the welding department five times during the past ten years. The college is now in a position to give instruction in all classes of gas and metal arc welding, and instruction in the applications of each type of welding.

Fifth Annual Conference on Welding

The Fifth Annual Conference on Welding was held at Purdue University under the direction of the Engineering Extension Department and the Department of Practical Mechanics, on December 11 to 13. The purpose of this conference was to bring together at Purdue University a group of men interested in the latest developments and possibilities of welding in its various forms.

The program included demonstrations, exhibitions and papers on structural steel welding, pipe line welding, atomic hydrogen welding, training of welders, welding of thin sheets, oxy-acetylene cutting, building machine tools, jigs and fixtures, welding of copper and inspection and testing of welds.

Back Issues of the Journal

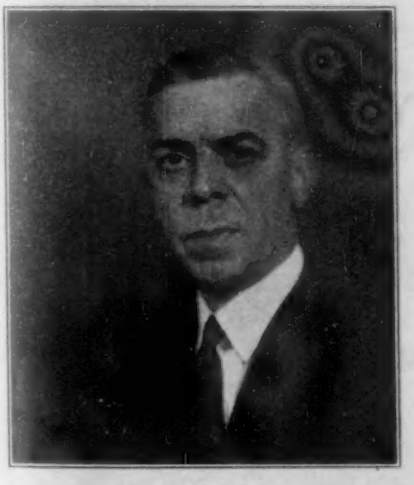
The Society has been requested to secure if possible copies of the Bound Volumes of its Journal for the years 1922 and 1923. Any member desiring to sell his copies at $5.00 per volume should communicate with the

Secretary. A price of 50c. per copy will be paid for copies of the April, 1929, issue.

Our Treasurer Honored

One of the new honors bestowed on our worthy treasurer, C. A. McCune, was his recent election as president of the International Acetylene Association for the coming year.

Mr. McCune has served as treasurer of the American Welding Society since 1923 and as its president, 1922 to 1923. He has been identified with many activities of the American Welding Society and its research department, the American Bureau of Welding, having served as chairman of the Membership Committee, chairman of the Welding Wire Specifications Committee and chairman of the Exposition Committee. He was, also,



one of the three trustees of the Miller Medal Board of Award. Mr. McCune has been identified with the welding industry since 1906. In that year he took up the study of acetylene as assistant engineer of the Commercial Acetylene Company, of which organization he later became chief engineer. During the last decade he has been identified with the Page Steel & Wire Company and the American Chain Company. His position with the latter company is now director of research.

He served for several years as chairman of the Oxy-Acetylene Committee of the International Acetylene Association. As its president he brings to that organization a high quality of leadership, energy and enthusiasm. The American Welding Society wishes him success in his duties.

New Members Secured in "Member for Member Membership Campaign," November 16th to December 15th, 1929

Class B

	Proposer
Brewster, M. W.	E. Vom Steeg
Hallen, M.	Wm. Spraragen
Jones, C. L.	A. F. Keogh
Knerr, H. C.	J. J. Crowe
Matthews, H. A.	H. E. Gannett
Mattice, E. S.	J. H. Wallis
Montfort, G. H.	W. A. F. Millinger
Morrison, R. L.	G. W. Swan
Nyquist, C. J.	S. H. Taylor, Jr.
Raney, J. E.	H. P. Peabody
Royer, H. B.	A. F. Keogh
Schill, H. J.	Robert Siemer

Class C

	Proposer
Beazell, R. F.	Wm. Spraragen
Bernard, A.	Wm. Spraragen
Brodsky, A. M.	
Collins, L. F.	Wm. Spraragen
Davis, H. L.	Wm. Spraragen
Frank, M. M.	
Geoghan, J. R.	A. F. Keogh
Green, J. B.	Wm. Spraragen
Hanson, L. W.	A. J. Hand
Hargest, W. J.	A. G. Oehler
Holt, R. W.	Wm. Spraragen
Kannar, J. L.	A. F. Keogh
Kelly, Wm. E.	S. H. Taylor, Jr.
Marshall, J. R.	F. E. VanCleave
McLean, Gordon	Wm. Spraragen
Morrisey, J. P.	J. G. Norton
Paterson, J. H.	G. D. Fish
Pfister, E. J.	A. F. Davis
Raffey, A.	
Rapp, E. F.	E. S. Hebeler
Sacks, J. J.	Wm. Spraragen
Sarsfield, M. W.	Wm. Spraragen
Shuler, E. J.	Wm. Spraragen
Summers, Dana	Wm. Spraragen
Taylor, S. H., Jr.	E. S. McKittrick
Walker, J. P.	Wm. Spraragen
Wiesner, A. J.	E. S. Hebeler
Young, E. H.	Ernst Bauer

Class D

	Proposer		Proposer
Brandon, C.	F. E. VanCleave	McDonald, H.	C. F. Meagher
Burdette, L.	A. F. Keogh	Smith, Melvin	A. F. Keogh
DeLong, C. E.	Daniel Zinck	Sutphen, M. L.	H. W. Saunders
Hicks, S. J.	E. F. VanCleave	Weideman, R.	
Hurley, Wm.	A. F. Keogh	Wilson, Ted	B. M. Shimkin
Madison, R. B.	Robert Siemer	Zelasko, M.	M. S. Hendricks
McCarthy, B. W.	G. W. Swan		

Member for Member Campaign

Closes Feb. 1

Have You Secured Your New Member?

SECTION ACTIVITIES

Chicago

Welding heating piping was the general subject presented at the December meeting of the Chicago Section, held Friday, December 6, which was attended by over two hunderd men interested in the applications of the welding torch. The subject was presented in a dialog between a steamfitting contractor and an applicant for a job as welder in the contractor's organization. The knowledge essential to a pipe welder was brought out by questions put by the contractor and answered by the applicant. Following the questions the applicant made a test weld in a piece of pipe, then cut coupons from it which were hammered in a vise to test the strength of the weld and to indicate the welder's ability to make a sound deposit. The welding and testing of the pipe was the demonstration, which has become a feature of the meetings of the Chicago Section this year. Mr. F. Outcault of the Linde Air Products Company acted as the contractor and Mr. E. S. Brewer of the Air Reduction Sales Company answered his questions and made the demonstration weld.

Cleveland

The October meeting of the Cleveland Section was held on the 17th. The attendance numbered three hundred, which was made up of three groups, A.I.E.E., C.E.S., and A.W.S.

The subject was the first Cleveland presentation of the new Portable Photophone projector perfected by the General Electric Company. In this film Dr. Irvin Langmuir showed through research work how atomic hydrogen welding was introduced.

Detroit

Honorable O. E. Fleming, K.C., President, Canadian Deep Waterways Association, spoke before the members of the Detroit Section at a meeting held on December 3. His talk, which was very interesting, was on the St. Lawrence Waterway.

Los Angeles

The December meeting of the Los Angeles Section, held on the 10th, was in the form of a social dinner and theatre party. The hosts of the evening were the Pacific Iron and Steel Corp., and the motion picture star, Edward Everett Horton, whose theatre they attended. The members of the Section were, in turn, hosts to several construction engineers from the local motion picture industries and a short talk was given by Mr. E. S. McKittrick of the Union Engineering Company, on "A Silent Method of Construction in the Talkies."

Northern New York

The Northern New York Section held a meeting on December 5 at the General Electric plant in Schenectady. Mr. R. L. Browne was the speaker. He gave a lecture and demonstration of thermit welding. Numerous lantern slides were used showing views of thermit welds on shafting and marine applications.

Motion picture films of thermit welding of street railway track and of welding the stern post of the U. S. S. Northern Pacific in 1918 were shown.

Western New York

The regular monthly meeting held on December 9 was a joint meeting with the American Society of Civil Engineers, American Society of Heating and Ventilating Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers and Society of Automotive Engineers.

The speaker was Mr. S. Martin, Jr., of the Welding Engineering Dept., General Electric Company. His subject was "Atomic Hydrogen Arc Welding." He used a portable photophone giving a talking moving picture by Dr. Irvin Langmuir, Associate Research Director of the General Electric Company.

The wide interest in this very new process of electric welding was indicated by an audience of some 350 engineers, who appeared desirous of seeing and hearing the entire story from beginning to end. This indicated that there is no difficulty in obtaining a satisfactory audience when the subject is interesting and instructive.

The next meeting will be held at the same place, *i.e.*, in the rooms of the Engineering Society of Buffalo, at the Hotel Statler, Buffalo. This meeting will be on January 13 and under the auspices of the Linde Air Products Company.

Portland

The Portland Section held its October meeting on the 30th. The program was in charge of Mr. W. P. Kellogg of the Portland Oxygen & Hydrogen Company, who commenced with a brief history of the origin and the successive steps in manufacture of oxygen and acetylene gases. Mr. Kellogg was ably assisted by Mr. Beckwith, who performed various miracles with liquid oxygen, and by Mr. Hall, who made the liquid oxygen.

These feats were followed by a film produced by the Bureau of Mines in collaboration with the Air Reduction Sales Company. The film graphically explained the present methods of obtaining oxygen and acetylene for commercial purposes, and showed a good many uses of the oxy-acetylene flame.

The December 5 meeting was given over to "Structural Steel Arc Welding," which was presented by Mr. A. G. Bissell, Consulting Engineer, of Seattle, Washington. The talk was illustrated with lantern slides, among which were shown examples of buildings which were erected the past year by arc welding. The talk and illustrations proved to be very interesting and instructive.

For January and Febuary of next year, dates of which have not yet been set, two programs have been arranged. The Metal and Thermit Corporation of South San Francisco,

Calif., will show two reels of moving picture films showing thermit rail welding, and one of ship repair. Mr. William Aldrich of the Thermit Department will give a talk on thermit welding. The Smith Welding Equipment Company will show motion pictures and will discuss the subject of Acetylene Welding.

San Francisco

The subject of the program for the November 25 meeting of the San Francisco Section was Field Welding of Pipe Lines. The following well known men presented talks on this subject: Mr. R. S. Fuller, Engineer of Transmission and Distribution, Pacific Gas and Electric Company; Mr. W. T. Graham, Superintendent of Field Welding, A. O. Smith Corporation; and Mr. C. E. Rhein, Sales Engineer, Linde Air Products Company. In addition to these speakers, discussion was presented by several individuals who are actively interested in the subject. As was promised, this was a worth while meeting and the Program Committee was very fortunate in securing these well known speakers for the meeting.

The December meeting of the San Francisco Section was held on the 13th at Oakland Central High School. Dinner was served at the Athens Athletic Club, Oakland, Calif. Mr. G. T. Kerr, of Hall Scott Motor Co., Berkeley, Calif., spoke on "Building Up of Dies by Welding." An explanation by a representative of the General Electric Co. on the History of the Atomic Hydrogen Arc, was followed by a demonstration of this machine in the welding class room.

New York

The regular monthly meeting of the New York Section was held on December 10. The subject of the evening was "Welding of Metals." Mr. W. B. Miller of the Union Carbide and Carbon Research Laboratories, and Mr. G. R. Brophy of the General Electric Company spoke on the above subject, after which a lively discussion took place. A "talkie" film was shown of the Atomic Hydrogen Arc Welding process. There were 65 people present.

A joint meeting with the American Society of Mechanical Engineers will be held on January 7. Mr. J. R. Weaver of the Westinghouse Electric & Manufacturing Company will talk on "New Methods of Building Machine Tools, Jigs and Fixtures by Means of Arc Welding." Mr. F. E. Rogers of the Air Reduction Sales Company will be the other speaker of the evening. His talk will be on "Cutting Steel Shapes with Mechanically-Operated Torches."

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be addressed to the number indicated in each case and mailed to Society headquarters.*

SERVICES AVAILABLE

A-86. Structural engineer now Sales Manager of well-known manufacturer of structural steel and ornamental iron, using considerable arc welding, desires to form a connection with a manufacturer specializing in, or wishing to specialize, in the manufacture and erection of structural steel and ornamental iron by welding methods. Would desire to make some investment.

Automatic Arc Welding*

W. L. WARNER†

IN its broadest sense, welding embraces a number of processes, each of which possesses essential differences from its neighbor, but all have for their ultimate object the joining of metals in some form. The present discussion is confined exclusively to electric arc welding, with special reference to the use of automatic machinery for performing the welding operation.

The joint itself may be of several types, the commonest of which are the butt and lap joints. We are concerned primarily with the butt joint in the present instance.

The Fusion Welding Process

The process of fusion welding requires that the parts to be joined be brought up usually from room temperature to a molten condition, over a certain portion of their extent. The temperature of this molten condition varies with different metals, and the temperature limits between which the fusion operation must be performed are narrower with some metals than with others.

In order to accomplish a thorough fusion between parts to be welded a certain amount of time is required, depending on the nature of the material and the effective heating power of the welding flame. Probably more radical changes take place during this brief time interval than in any other equivalent cycle of metal handling. The change from room temperature to the molten condition is almost instantaneous and the cooling cycle is necessarily short, due to the very local extent of the molten zone. This means that the metal is heated to above the melting point and returned again to a solid condition, in the space of a very few seconds.

To the layman, the resulting joint must obviously be something quite different from the material it joins and the metallurgist will confirm this viewpoint. For many years we have been accustomed to see sheet edges lapped and held together by a row of rivets. Thus there has been a feeling that the butt joint which has been made, so smoothly and quickly, must be only a substitute and not to be relied upon. But, as a matter of fact, the welded joint will develop at least 85 per cent of the strength of the sheet joined and usually the sheet will yield before the welded joint.

This feeling has served to make industry more critical of welded joints than of other types, so that requirements for efficiency are higher and design allowances less liberal. However, design allowances are not yet

*Paper presented at Fall Meeting, A. W. S., September, 1929.

†Industrial Heating & Welding Eng. Dept., General Electric Co.

as liberal as they should be, assuming that proper procedure control methods are exercised.

The welding process has developed rapidly during the past decade and is still being further developed. New methods and procedures are being perfected, with the one great object in view of obtaining maximum efficiency with least effort, time and cost. In many instances these objects have been quite fully realized.

The Arc Welding Operation

The parts or sheets to be joined are placed in the same plane, with edges butted together where the weld is to be made and, usually, clamped on to a suitable backing device for the weld. An arc is struck and maintained, between a metal electrode and the joint edges. This arc is moved continuously at the proper speed from one end of the joint to the other, fusing the two edges together.

It is essential that the joint be backed up tightly by some means to prevent the molten metal from running through, forming protrusions on the back of the joint and also leaving holes in the joint.

This backing up device must fulfill several requirements. The material must be of such a nature that it will not melt and fuse to the back of the joint. Copper bar stock or strip is quite generally used for this backing, due to its high heat conducting properties and durability for this service. The backing up device must also be somewhat flexible and yet exert sufficient force to clamp and hold the joint edges evenly together. In some cases it may be possible to butt-weld thin sheets without a backing, but usually variations in preparation of the joint edges on a production basis prevent a successful job.

When heat is applied to steel or iron a distortion or displacement occurs in three directions. As the heat is removed the material tends to return to normal. The amount of this expansion and contraction depends upon the rate of application of the heat and the length of time during which the heat is applied.

In welding, an intense heat is applied at a point on the metal surface and is then moved rapidly along, causing a small part of the metal to come to the melting point and solidify, in a fraction of a second, as the arc passes over it. This condition is such that the melted metal does not return to the original temperature as quickly as the heat was applied, so that there is a cumulative effect produced. This effect produces a net expansion in three directions, with respect to the weld, longitudinally, laterally and vertically.

If two flat strips are placed together and a weld is started at one end, it will be found that the joint edges begin to separate after the arc has traveled about a third of the way down the seam. This separation will continue until the joint edges are apart a distance greater than the electrode diameter, if the welding is continued. To prevent this separation when welding flat strips, a tack weld is usually placed at each end of the joint. This separation, or moving apart of the plates, is caused by the combined longitudinal and lateral expansion. Its amount depends

upon the lateral width of the pieces being welded, the amount of welding heat, and the welding speed. This separation does not occur, to the same degree, in the thicker plates, i. e., above ¼ in. thick.

Assuming that the two strips have been tack welded and the weld made, if the welded piece is taken from the machine immediately it will be curved in shape longitudinally and flat laterally. If, however, the welded piece is left in the clamp until cold a portion of this distortion will be eliminated. Welds of this type made on cylindrical drums or rectangular

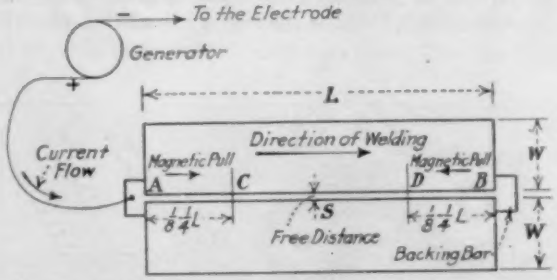


FIG. 1. DIAGRAM SHOWING MAGNETIC PULL ON AN ARC BUTT WELDING TWO PIECES OF PLATE

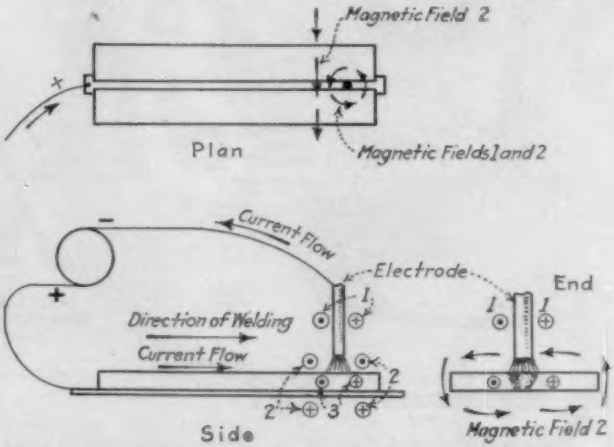


FIG. 2. DIAGRAM SHOWING MAGNETIC FIELDS CAUSED BY AN ARC BUTT WELDING TWO PIECES OF PLATE

box structures do not show this distortion due, to the vertical and lateral stiffening effect of the shape of the piece.

With these conditions in mind, one can readily see the importance of suitable clamping apparatus and procedure, for welding thin sheet metal successfully.

Another condition, which is apt to cause trouble unless controlled, is the magnetic effect produced by the electric current passing through the arc. It is generally understood that, when an electric current passes

through a conductor, a magnetic field of a certain intensity is set up around the conductor and in a certain direction. This magnetic field tends to travel in the path of least resistance and resists deflection from this path, in proportion to its intensity.

It is neither possible nor desirable to discuss these electro-magnetic conditions in detail except in so far as to try to explain certain methods now used to control these conditions..

In Fig. 1 is shown, in plan, a weld being made between two pieces of plate, the joint extending from *A* to *B*. This sketch shows the weld as

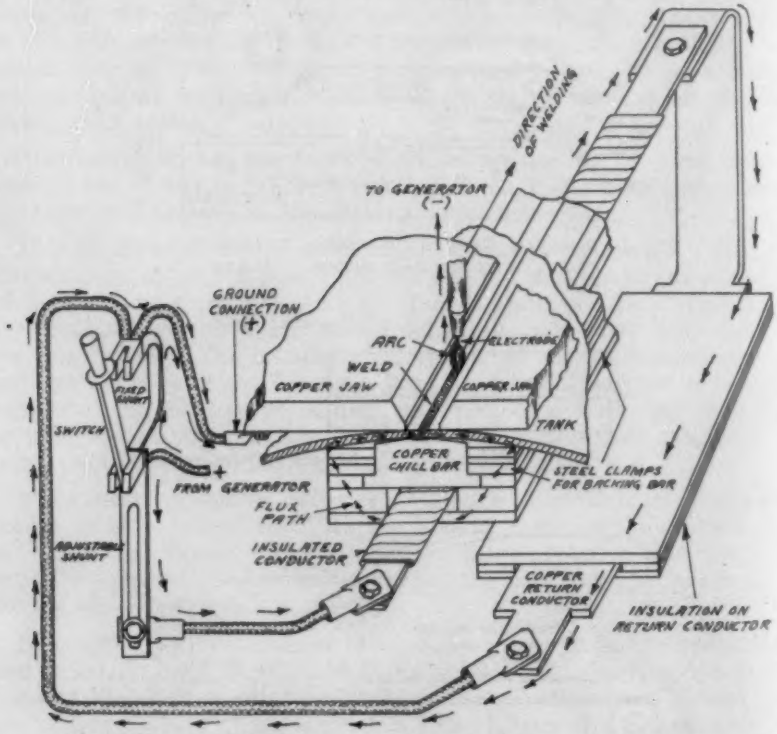


FIG. 3. MAGNETIC CONTROL DEVICE FOR STABILIZING THE WELDING ARC

progressing from *A* to *B*, with the ground connection from the generator made to the copper backing bar at end *A*. In practice, this is generally the situation for magnetic control purposes.

As the weld progresses from *A* to *B*, a careful observation of the arc and arc flame will show a decided forward pull of both arc stream and flame, for approximately ⅛ to ¼ of the length of the seam. The exact distance over which the pull occurs is variable with the welding conditions so that it is impossible to set a definite value. This forward pull is a maximum at the start of the weld and becomes almost zero at about the point *C*. From this point to the point *D*, the pull of

the arc is gradually changing, from a slight forward pull to a slight backward pull, and is most stable between these points. From the point *D* to the end of the joint at *B* the backward pull increases rapidly; until, within an inch or so from the end, this tendency to pull back may often be sufficient to extinguish the arc.

Obviously, this varying condition turns toward instability of the arc and may be responsible for lack of fusion, porosity, and an unevenly welded joint. In general it may be said that, with a copper backing bar, the arc will have a tendency to pull away from the ground connection. The amount of this pull, which depends upon the strength of the mag-

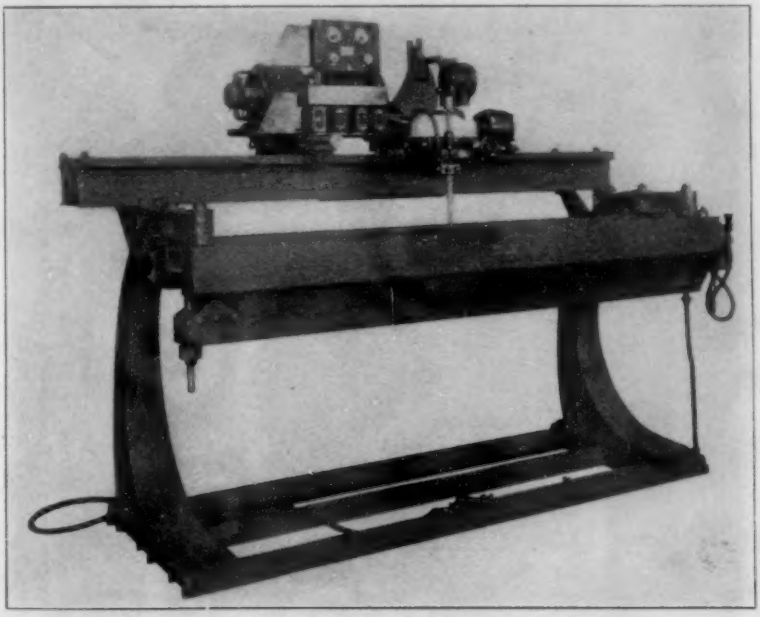


FIG. 4. AUTOMATIC ARC WELDING MACHINE FOR STRAIGHT SEAMS ON THIN SHEETS

netic field causing the pull, will vary with the amount of welding current, size of pieces being welded, free distance between joint edges *S*, and position of electrode on the joint.

A magnetic field is set up, in the plane of the pieces being joined, in addition to that circumferentially around the electrode and the plates being joined. Fig. 2 shows the location and direction of the magnetic fields set-up by the welding current of the arc in welding two pieces of plate. Fig. 2(A) is a side view, 2(B) an end view, and 2(C) a plan view. Field (1) is set up around the electrode, Field (2) around the plates being welded, and Field (3) in the plates adjacent to the arc and in direction similar to Field (1). Apparently Field (3), which tends to maintain itself in the plates, causes the arc to draw away from either end of the weld. As shown in Fig. 2(C), the flux, passing across the

FIG. 5. PANORAMIC PHOTOMICROGRAPH OF AN ARC WELD ACROSS THE FUSION ZONE

FIG. 6. PHOTOMICROGRAPHS TAKEN FROM BRIGHT, DEEP-DRAWING STEEL, MAGNIFICATION 100 DIAMETERS. (IN REPRODUCING, A REDUCTION OF 22 PER CENT WAS MADE.) THE DIAGRAM AT RIGHT SHOWS LOCATIONS OF (1) BASE METAL; (2) CENTER, HEATED ZONE; (3) FUSION ZONE; (4) WELD METAL

seam between the arc and the end of the seam, increases rapidly in density as the ends of the plates are approached. Due to this construction of this field between the arc and the starting or finishing ends of the plates, the drawing or pulling effect is produced; which, usually, is less noticeable at the start than that produced near the finish end of the weld. Obviously, it is not possible to remove these fields from the welding operation, so that it is necessary to use some external control means for overcoming these magnetic effects.

Such a control scheme has been developed by the General Electric Com-

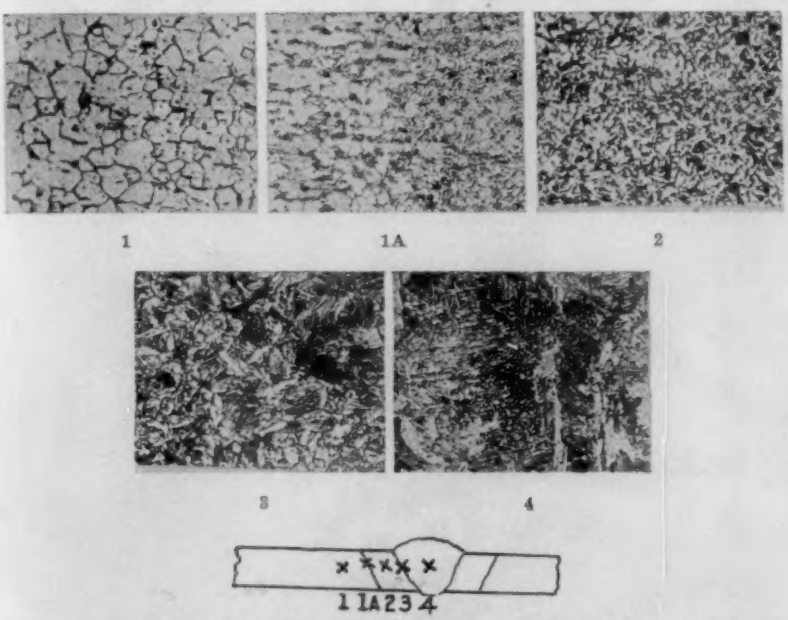


FIG. 7. PHOTOMICROGRAPHS TAKEN FROM BLUE ANNEALED STEEL, MAGNIFICATION 100 DIAMETERS. (IN REPRODUCING, A REDUCTION OF 32 PER CENT WAS MADE.) THE DIAGRAM ABOVE SHOWS LOCATIONS OF (1) BASE METAL; (1A) EDGE, HEATED ZONE; (2) CENTER, HEATED ZONE; (3) FUSION ZONE; (4) WELD METAL

pany and is shown on Fig. 3. This scheme consists of imposing a magnetic field, of the proper direction and intensity, such as to cause the arc to become least affected by magnetic fields (1) and (3), and any others which may be set up in the clamping device. Field (2) tends to cause the arc to draw slightly ahead which is desirable.

As will be seen from the illustration, the work, or pieces to be welded, is held in place by a pair of copper jaws, the copper chill bar and the corners of the steel strips used in building up the complete backing bar. Beneath the copper chill bar is an insulated conductor, so connected that part of the welding current may be shunted through it.

When the current flows through the insulated conductor under the

chill bar in the direction of welding, in this case away from the observer, a magnetic field is set up in the plates being welded, in the direction indicated by the arrows; and travels approximately in the path as indicated, which is parallel to Field (2) already shown. It is essential that the work and the steel edges of the backing bar make contact. Otherwise, the high reluctance of the air gap, when there is no contact, will reduce the amount of flux through the work and render the magnetic control ineffective.

The magnetic flux in the work, and across the seam at the joint being welded, acts upon the arc in the same manner as the field of a direct current motor acts on an armature conductor. Applying the same

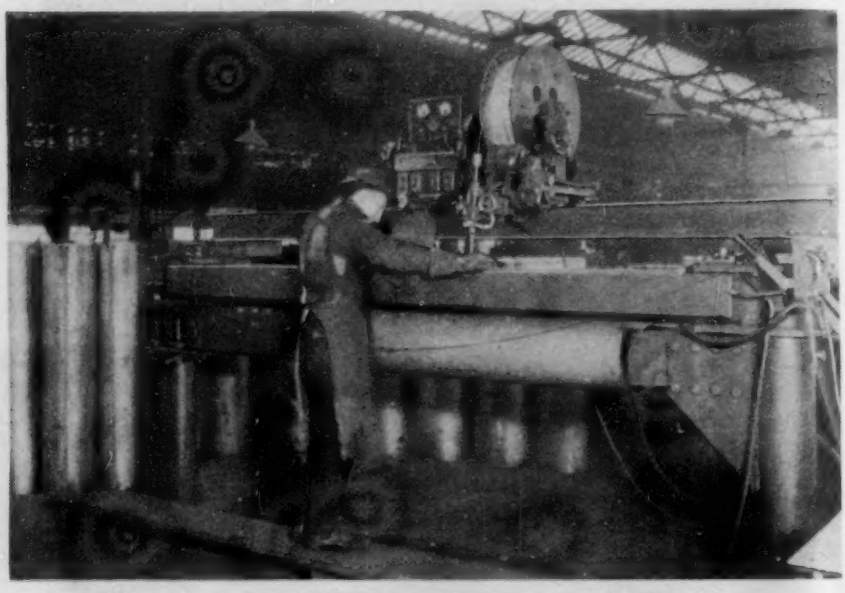


FIG. 8. WELDING SIDE SEAMS OF RANGE BOILERS

magnetic laws, it will be seen that this field will tend to blow the arc in the direction in which it is traveling. In order to render this control effective, it is necessary that the insulated conductor be so placed that the magnetic controlling field is caused to travel, during part of its path, through the work and across the seam being welded.

In Fig. 4 is shown a 6 ft. machine, for straight seams of 14 gage sheet and below in thickness, equipped with a pneumatic clamp for holding the joint edges during welding, and the magnetic control device above described. The magnetic control switch, at the right end corresponds to the switch shown in Fig. 3.

With reference to the weld itself, and the character of the adjoining metal, Fig. 5 shows a photomicrograph of a typical cross section, originally at 100 diameters, extending from the interior of the weld across the

heated zone to the base metal a distance of 0.56 in. It will be noted that the heating effect of the arc extends into the base metal about ¼ in. from the edge of the deposited metal. Of this zone, only about ¼ of it, or 1/16 in., shows the effect of high heat in the form of the "Wiedmanstaaten structure." This section was taken from a weld on ¼-in. plate, welded with a 3/16-in. electrode, using about 350 amp., at a speed of approximately 6 in. per min.

The microscopic sections in Fig. 6 and 7 were taken from welds made on 14 gage sheet at 29 in. per min. They show the structures at four

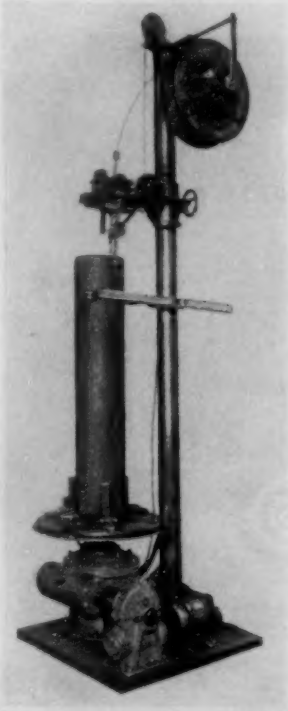


FIG. 9. AUTOMATIC ARC WELDING MACHINE FOR WELDING HEADS IN RANGE BOILERS IN VERTICAL POSITION

different points from the base metal to the deposited metal. Fig. 6 is a weld on bright, deep drawing steel of low carbon content. Photomicrograph 3, taken at the fusion zone, indicates quite a definite line of fusion marked by the small arrows. Fig. 7 is a weld on blue annealed sheet of slightly higher carbon content than the deep drawing steel. It will be noted that photomicrograph 3 of Fig. 7 does not indicate a definite line of fusion. In contrast to this comparison photomicrograph 1A of Fig. 7 shows the edge of the heat zone, which is more distinct

than the edge of the heat zone occurring in the welds on the deep drawing steel, Fig. 6.

It is planned to study the effect of welding alloy steel sheet containing manganese, chromium, nickel, and copper with different types of electrodes and compare the results with those obtained on ordinary carbon steel such as has been used here. This work has not been completed. The question of plate material suitable for welding has not been discussed thus far but from the general experience of the writer the same analysis of conditions is pertinent here as in the case of the heavier plates. It is necessary for best results that the carbon content be not over 0.25 per

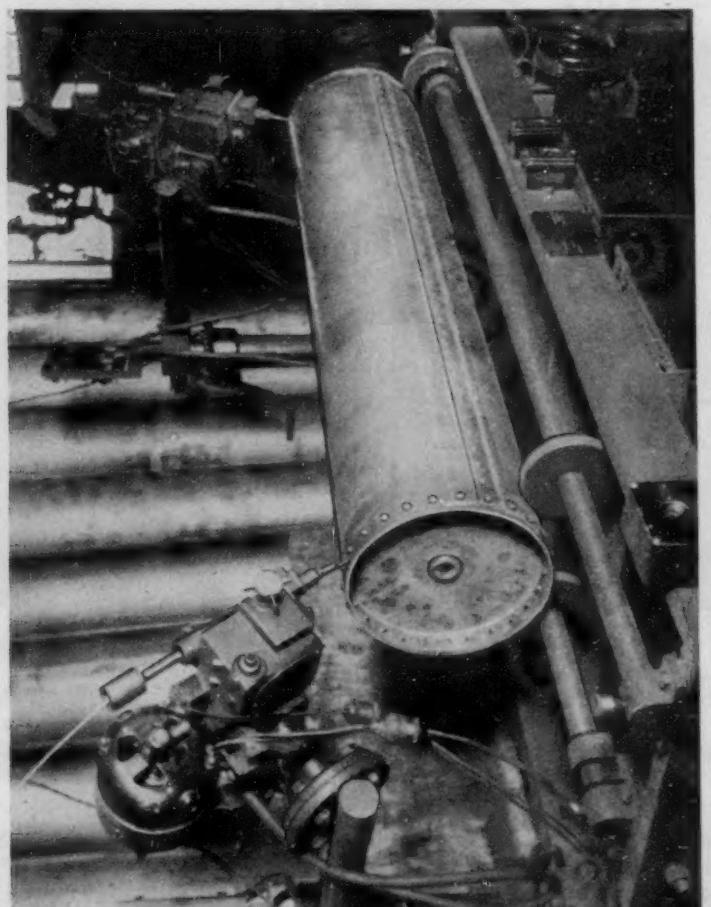


FIG. 10. AUTOMATIC ARC WELDING MACHINE FOR WELDING HEADS IN RANGE BOILERS IN HORIZONTAL POSITION

cent and that the material be free from laminations and segregations of impurities. The effect of manganese content of the plate on the character of the weld is not definitely known, but it is believed that up to limits of perhaps 1 1/3 per cent it is beneficial.

Mention has been made of thick and thin plate in this discussion, without a definite explanation of either, until one begins to wonder where the dividing line really is. The writer has arbitrarily considered ¼ in. thickness to be the beginning of heavy or thick plate. All thicknesses

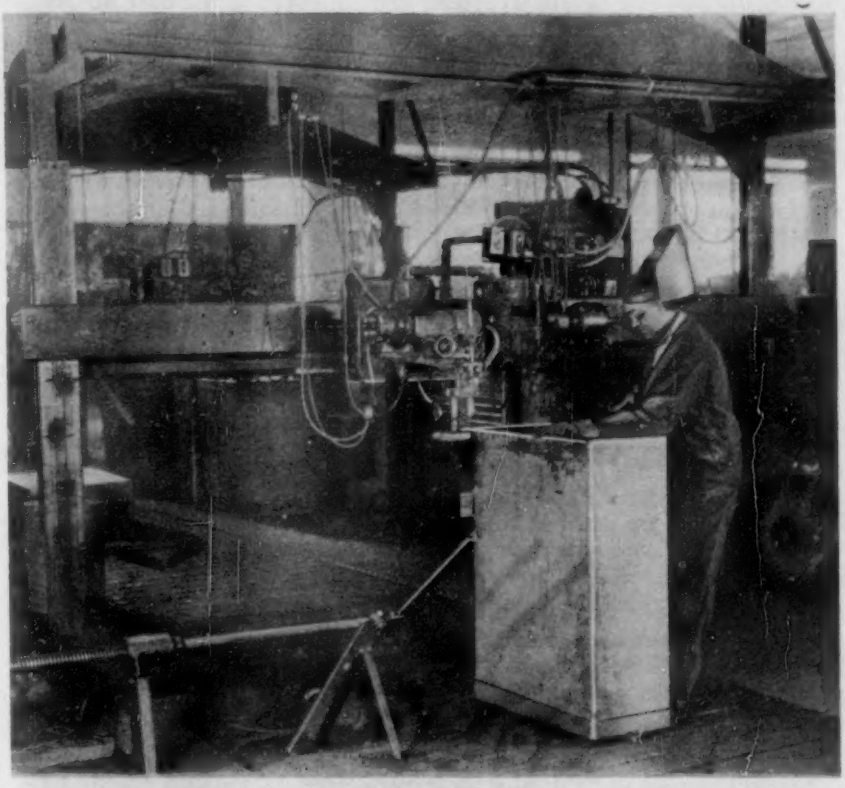


FIG. 11. AUTOMATIC ARC WELDING BOTTOMS IN WAYSIDE OIL VENDING TANKS

below that are considered as thin sheet. The thin sheet is welded by a single arc as against a series of arcs of the multiple arc process, for the thick plates; although a single arc may be used on the latter. Welds on thicknesses up to and including 5/16-in. plate can be completed with a single layer of deposit; but above that thickness two or more layers are desirable. The above designations of thick and thin plate have been used with this understanding. The welding of heavy plate is a separate study with different problems for solution.

Applications of Automatic Arc Welding

One of the first extensive uses of automatic arc welding for pipe construction was in 1924 and 1925 by the Western Pipe and Steel Company of San Francisco, Cal.

This pipe was built in the shop in 14 ft. sections 22 in. and 24 in. diameter of 3/16 in. and ¼ in. plate. The sheets were rolled to size and the longitudinal seam welded automatically with a single pass of the arc at a speed of about 4 or 5 in. per min. Two sections were hand welded together in the shop to form a 28-ft. length. All 28-ft. lengths were tested hydraulically before wrapping and shipment to the field for laying.

The use of welding for manufacturing household range boilers is also practiced extensively. In. Fig. 8 is shown the side seam being automatically welded at a speed of about 16 in. per min. for a butt weld on No. 14 gage sheet. The joint edges are clamped pneumatically and the magnetic control switch is shown on the right end of the machine.

After the shell is completed and the dished heads are inserted the circular welds are made by a machine such as shown in Fig. 9 or these seams may be welded with the tank in a horizontal position as shown in Fig 10.

The choice of either position is largely a question of design of tank, user's preference, and space available. The horizontal type is easier to load and the vertical type gives a better position to make the weld where the thickness of the head is appreciably greater than that of the shell.

In Fig. 11 wayside station oil vending tank bottoms are being welded at a speed of approximately 30 inches per minute. The welding heads are fixed in position and the tanks travel on a conveyor. The tank material is No. 15 gage and the electrode nozzles are fitted with guide rolls which keep the arc on the seam at the corner so that a combination corner edge weld is made. This operation requires very sensitive control and accurate fit of the heads into the shells.

Automobile rear axle housings are automatically arc welded in great numbers. These housings are pressed in two halves and welded, the two welds on one side being made simultaneously at a speed of approximately 22 in. per min. for each arc. The material is 3/16 in. thick and the weld penetrates about 2/3 through the joint making it oil tight and sufficiently strong for the service required.

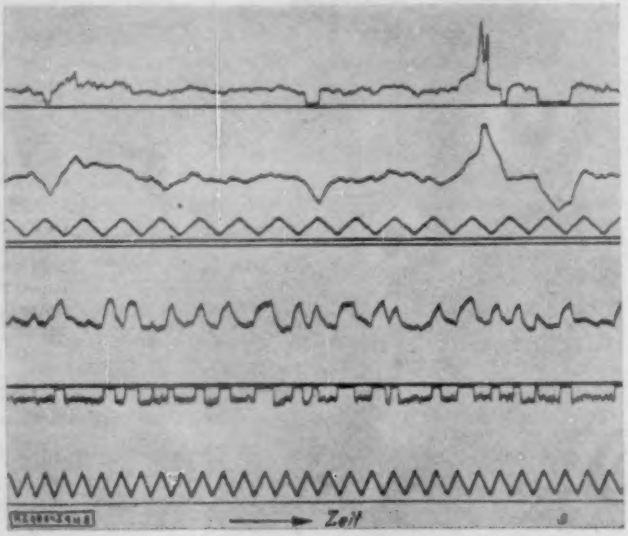
The welding of galvanized iron is performed at welding speeds somewhat higher than those used for the material without galvanizing. It is desirable to avoid full weld penetration of the joint on account of porosity caused by gas from the melted under coating. If full penetration is required then best results are obtained without backing. Under such conditions accuracy in the alignment of the joint edges is imperative.

In general the application of machine welding methods to thin sheets requires accurate preparation of the joint for welding, suitable methods of clamping, proper welding materials, both electrode and plate, intelligent supervision, and correct design. Beveling is usually not necessary or desirable for thicknesses below ¼ in.

Material Transference in the Welding Arc*

By A. Hilpert†

ALTHOUGH considerable has been known about the characteristics of the welding flame of the oxy-acetylene burner, up to a short time ago nothing much was known about the behavior of the metal welding arc, especially about the transfer of material from the electrode to the piece being worked on. It has been attempted to make this transfer



Figs. 1 and 2. Oscillograph Records in the Welding Process for Two Different Electrodes and the A. C. Voltage Curves Taken Simultaneously

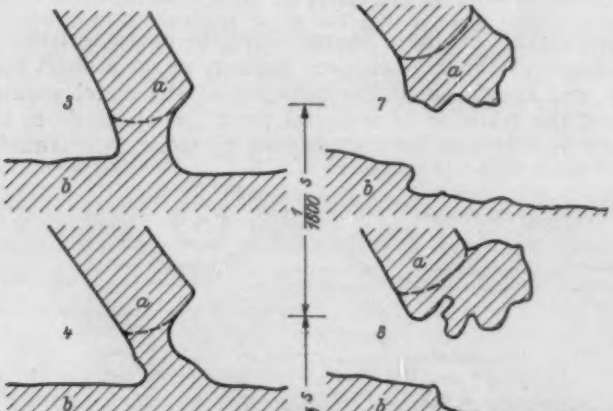
visible by means of photography, but a great deal of luck must be had to be able to get a picture of a passing drop, since this process in the metal arc proceeds with extraordinary rapidity. This phenomenon has been investigated with more results, by means of the oscillograph to obtain clearness, so that it could be concluded from the course of the welding voltage and amperage curve as to the duration and size of the drops. When a drop passes over it produces a short circuit, the current strength rises to the peak value, limited by the reactance of the machine, and the voltage drops to zero and remains at zero until the passage is complete and a new arc is formed.

In spite of the great sensitivity of the oscillograph, it is not always

*Reprinted from V. D. I. News Symposium on Welding Technique. Translated by H. Abrams, Thomas Research Laboratory, General Electric Company, Lynn, Massachusetts.

†Technische Hochschule, Charlottenbug 2, Berlin.

able to follow the extremely rapidly changing processes. Therefore, it was always desired to film the arc when it was found possible to take a great number of pictures per second. Thus, in the early part of 1927 the welding arc was filmed for the first time under the direction of Dr. Ing. A. Hilpert of the laboratory for welding technique at the Berlin



FIGS. 3 TO 10. DROP TRANSFER FROM ELECTRODE TO WELDING FRINGE IN FOUR SUCCESSIVE 1/1600 SEC. APART REFORMATIONS IN MICROSCOPIC ENLARGEMENT. (A) ELECTRODE. (B) WELDING FRINGE

Tech. High School. This was done with the apparatus of the film manufacturer, Ing. Thun, which could be operated at 800 exposures per second. The film, though unrolled at 1/40 speed, showed in no way, because of the overpowering brilliancy of the arc, how the metal passed over from the electrode to the work. It did show well, however, that in spite of the 40 fold drawing out of the arc it still moves around at a very lively pace.

Meanwhile, in America, films were made using the heat rays. The pictures of the welding arc were made on strongly red sensitive film behind the dense red filters. Therefore, due to the long time of exposure, it was only possible to make 60 exposures per second, so that the film could be unrolled at only ¼ of the speed. In spite of this, films made here for the first time showed the transfer of material. Much was left to be

desired as regards shape and path, however, due to the extremely rapid movement (60 exposures per second are too few).

Meanwhile, Thun was working on a new apparatus, with which he could make 4000 exposures per second. The material transfer was made clearly visible by this, since due to using a more intense source of light as a background, the material passing over appeared as silhouettes on the film.

After a few tests had shown the feasibility of the outfit, investigations of the transfer of material were planned out by the welding committee of the V. D. I., and at first, with bare electrode low carbon, on the negative pole of an automatic machine in order to obviate the uncertainty of the welder's hand.

Also, simultaneously with the film, oscillographs were made of the welding voltage and current and also of the voltage of an A. C. 50 cycle arc lamp. By comparison with the images it was now possible to follow the time passage of the individual drops and the welding voltage and current as well as the arc light duration.

By changing the welding voltage and keeping the current constant one could make a graph of the most practical voltage current for a given electrode and especially also of the relation of arc duration to drop transfer duration, which is important in welding for sufficient heating and penetration. Figs. 1 and 2 show sections for two different electrodes and the A. C. voltage curve of the A. C. lamp taken at the same time. Thus we are independent of the speed of the film and oscillagraph band. The distance from peak to peak in the A. C. wave represents 1/50 second; from this, the length of the drop duration, which is recognized by black streaks on the zero line, may be determined. In the oscillograph section, Fig. 1, the drop interval is slow; in Fig. 2 much faster.

From the approximately 3000 drops observed in the experiments, the longest had a duration of about 1/7 second, the shortest only about 1/2000 second. The films were taken at the rate of 1600 to 2400 exposures per second; for this reason the films could be shown at about 130 times the time. By means of this the most rapid processes were visible to the eye. In the main two types of drops were determined, the thread-shaped and the mushroom-shaped. In the thread-shaped drop the material goes over as a thread without thickening of the electrode end, in the mushroom-shaped drop, there is more or less thickening of the electrode end on which the drop dances around until it suddenly goes over to the material being welded.

How quickly these processes go on is shown in Figs. 3-10. Figs. 3-6 show a thread-shaped, 7-10 a mushroom-shaped transfer of the welding drops, and indeed Figs. 7-10 give the microscopic enlargement of four successive 1/1600 sec. apart reformations all lying close to one another. Within 1/1600 sec., therefore, the shape has become greatly altered. It is to be noted from this that a very great number of images must be worked within the investigation of the material transfer in arc welding.

I shall report on the latest developments of the material transfer in the welding arc at the convention of the V. D. I. committee on welding in Danzig on June 21.

Welded Boilers*

By E. R. Fish†

THE idea of fabricating high pressure steam boilers by welding processes is not new. It has, however, been practiced to a considerably greater extent abroad than in the United States. There have been some serious failures of welded boilers that have to a very great degree discouraged its use here. So far as the writer is aware, there are no high

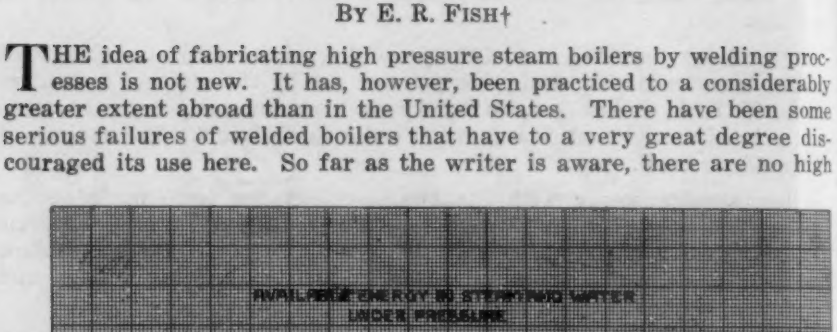


FIG. 1

pressure boilers constructed by the fusion welding process in this country but there are some forge welded ones. Therefore, so far as the adaptation of welding processes to actual boilers is concerned, there is but little to discuss. You will note that reference is made to high pressure boilers, for the above statements refer only to boilers which are designed to carry pressures in excess of fifteen pounds per square inch.

Low pressure boilers used practically exclusively for heating purposes are manufactured on a production scale in tremendous volume without the use of any riveting whatever. This, of course, involves only relatively

*Paper presented at Oct. 21, 1929, meeting of Philadelphia Section, A. W. S.

†Combustion Engineering Corp., New York.

light plate, rarely over 7/16 in. thick. The A. S. M. E. Boiler Code for Low Pressure Heating Boilers specifically recognizes the progress of the art by permitting this method of joining low carbon steel plates in fabricating boilers of this class. There are literally thousands of welded heating boilers in use with a very gratifyingly low record of failures. But it is with power boilers that we are now particularly concerned. First let us examine the hazards involved. As the pressure increases the boiling point of water rises. If the pressure be reduced, the stored heat immediately evaporates a portion of the water and if the reduction of pressure is sudden there is created an explosive action similar to that of gunpowder. Professor R. H. Thurston some years ago calculated the stored energy in boilers which very clearly illustrates why boiler failures are so disastrous.

This energy is divided between the steam and water. For each pound in weight, that in the steam is very much greater, at the usual operating pressures than in the water, but as the number of pounds of steam in a boiler is much less than the weight of water, the total energy in the latter is far greater than that in the steam and hence has the greatest destructive potentialities. To give an idea of these quantities, the following table has been prepared. These figures are approximate only and are not given as being exact.

When Reduced to Atmospheric Pressure and 212 Deg. Fahr.

Pres. by Gauge	Available Energy in Ft. Lb. In. One Lb. Water	One Lb. Steam	30,000 Lb.* Water	90 Cu. Ft.* Steam
5	146	16,800	4,380,000	57,500
25	1,600	54,000	48,000,000	463,000
50	3,875	78,800	116,250,000	1,064,000
75	6,050	94,800	181,500,000	1,740,000
100	8,100	106,000	243,000,000	2,460,000
200	15,000	130,000	450,000,000	5,475,000
500	30,100	166,000	903,000,000	16,400,000
1,000	49,000	180,000	1,470,000,000	35,650,000

*Typical 500-hp. water tube boiler.

One of Dr. Thurston's concrete examples is of a watertube boiler of 3000 sq. ft. of heating surface, ordinarily referred to as a 300 hp. size, and at 100 lb. working pressure, a very low one today, in which there would be available stored energy in the water and steam of nearly 110,000,000 ft.-lb. If suddenly released and all applied to moving the boiler structure, this energy could project the boiler to a height of over 2000 ft.

It will be evident therefore that the destructive potentialities of high pressures are very much greater than at the lower pressures. It is because of this consideration of disastrous possibilities alone, that has deterred those in authority from heretofore accepting any except forge welding in the construction of high pressure boilers. Records are replete with failures of autogenously welded pressure containers, the reasons for which may be attributed to the relative inexpensiveness and ease with which anyone can set up a welding shop, and through the rapid expansion of the use of welding in fabricating containers and pressure vessels of many kinds. This has resulted in the establishment of many shops to fabricate vessels of this sort, frequently without proper precautions as

to the competency of the welders and methods and often without an appreciation of the responsibilities involved. In addition, there has been the necessity of learning by experience, by even the most conscientious and painstaking fabricators how to solve the problems that developed. It is now recognized that sufficient progress has been made to justify serious consideration of the application of this kind of welding as it relates to boilers. But it may be asked, why the necessity for departing from the long accepted and practiced method of joining plates by tried and true riveting? There are two reasons.

(1) The rapid development of power plant practice, particularly the adoption of the steam turbine, made unforeseen demands on the boiler

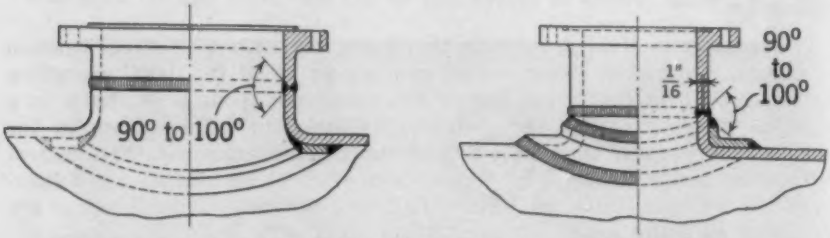


FIG. 2. METHODS OF WELDING ON NOZZLES AND REINFORCING THE OPENINGS

makers. Unheard of volumes of steam per hour were insistently demanded. When reciprocating slow speed engines were the prime movers, the engine room was the dominating part of a power plant as regards space. Pressures and steam temperatures were also limited. But the turbine entirely upset the situation. Requiring only possibly one-tenth the space needed by the old engines of the same capacity, the boiler room became dominant as to space, and efforts were directed to getting more and more steam from single units both by increasing the steaming capacity and the size of boilers. Had that been the limit of the demand it would not have been so hard on the boiler manufacturer, but the economy of and consequent demand for higher and higher pressures very greatly complicated the manufacturing problems which had to be faced. It is the cylindrical drums that constitute the greatest difficulty. Practical considerations limit the thickness of plate which can be satisfactorily riveted to about 2½ in., and there are but few shops that can go that high. Couple this with shell lengths up to 40 ft. or more and it becomes evident such structures are not easily made. For riveted construction, the usual diameters of drums therefore limit possible pressures to the order of 600 lb. sq. in., which, however, is now not regarded as very high. There are a dozen or more large units running today at 1200 lb. to 1400 lb. and three in process of installation to carry 1840 lb. The thickness of shells for such pressures is over 5 in. quite beyond any possibility of riveting. Up to the present all such are seamless, forged from a single ingot with the heads integral. However, high pressure chambers for oil refineries with wall thicknesses up to 5 or 6 in. have been fabricated by fusion welding. All such are made of several plates formed to shape hot and rigidly held in place while being worked on.

There are a great number of pressure stills of this type in use and the reported failures are very few. This is excellent evidence of the sufficiency of good welding.

(2) The mysterious cracking of plates of boiler drums, at first in some isolated and fairly well defined localities and later much more widely distributed, led to investigations that indicated quite positively that certain water characteristics are the principal causes of this cracking which always occurs where plates, rivets or tubes are in close contact. This theory has become generally known as caustic embrittlement and will be referred to hereafter as plate embrittlement.

It has been the thought of some engineers that the elimination of riveted construction would avoid trouble of this kind. However, it can be greatly minimized, if indeed not entirely avoided, by inside calking as is now quite generally practiced. The need for welding instead of riveting in order to prevent possible embrittlement, in the plate thicknesses that admit of either method of construction, is therefore not necessarily demanded although some prefer not to take any chances whatever. The possibility of this phenomenon appearing in all types

FIG. 3. PREPARATION OF PLATES FOR ELECTRIC WELDING PRESSURE STILL

of fabrication is always present at the tube holes, since the method of inserting and rolling tubes is identical for all.

The applications of welding to boiler fabrication may be divided into two principal classes with a possible third and fourth minor ones—forge or hammer welding, autogenous or fusion welding, electric resistance welding and thermit. The former is hoary with age, having been used since the beginning of the art of the working of iron and steel. However, the problems involved in welding the edges of long plates is quite a different matter from that of limited areas. But the reasonable

certainty with which the edges of plates may be joined by this process caused it to be permitted although with restrictions. The quality of the steel best suited to this purpose is such as to give physical characteristics less than the regular flange or fire box qualities. To be readily weldable the carbon content must not exceed .15 per cent and in consequence the tensile strength runs from 45,000 lb. to 55,000 lb. as against a range of 55,000 lb.-65,000 lb. for firebox quality. The maximum thickness of plate that can be forge welded is about 2 in. and present facilities limit the length to 30 ft. It will be seen therefore that this method, as applied to drums is limited to pressures of about 500 lb. It is also used to a con-

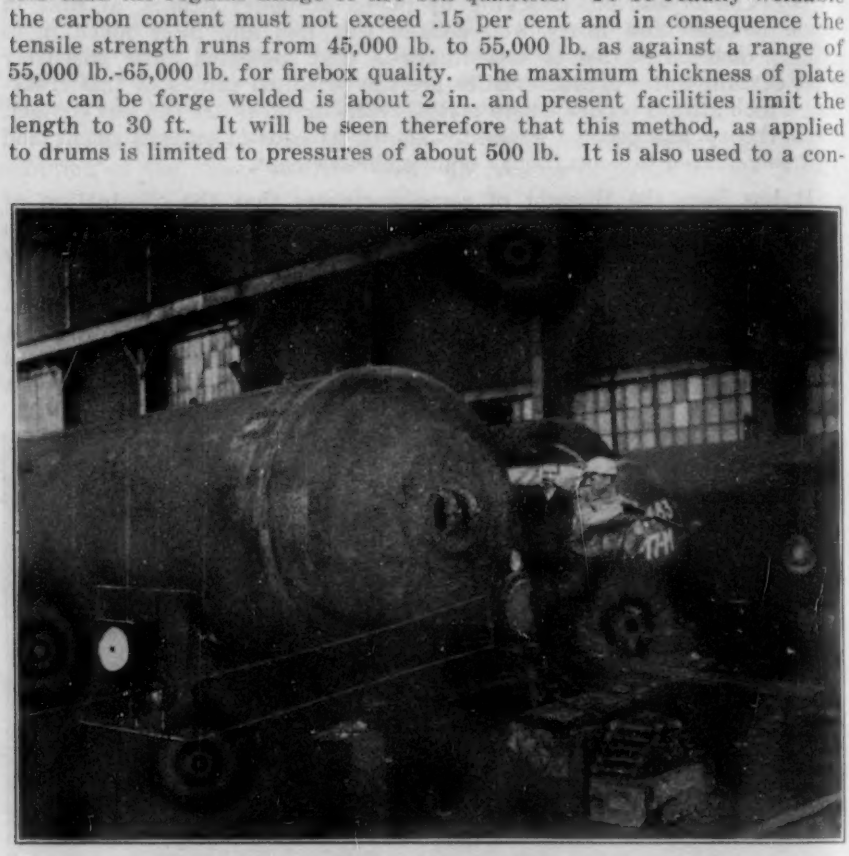


FIG. 4. TESTING WELDED VESSEL BY HAMMER METHOD

siderable extent in the manufacture of headers for watertube boilers but that is quite a specialized branch. Recognizing that there is some uncertainty as to the integrity of the weld the unit stress to be used in making calculations is limited to 7000 lb. as against 11,000 lb. for riveted joints and flange or firebox quality of plate.

The second welding process is the autogenous, either electric or oxy-acetylene, wherein extraneous metal is introduced to affect the bond between the edges. It will be appreciated that the thicknesses concerned are such that the weld metal must be deposited by a series of operations and that its mass is considerable. In the course of its operation a boiler is subjected to many unmeasureable stresses and distortions of shape due to pressure and temperature changes. It is because of these that ductile mate-

rial is so essential. It is imperative that the weld metal shall partake to a reasonable degree of the physical characteristics of the base metal. Only in this way can freedom from the effect of the localization of the unknown stresses be assured. Until very recently the character of the deposited metal has been uncertain and variable. Improvements in both methods and material now make it possible to meet the requirements. In order to insure uniformity in such large welds, automatic welding machines are highly desirable although not absolutely necessary. Fortunately it is not likely that there will be defects at the same place in each of the layers, so the risk of a poor weld is minimized.

The third method which is of very limited scope is electric resistance welding, which has been recognized as the equivalent of forge welding. It is as yet applicable only to the joining of very small surfaces and

FIG. 5. FORGE AND HAMMER WELDED BOILER DRUMS

hence is not included as one of the methods for fabricating large drums or other parts.

The fourth method of welding the edges of plates is by the use of thermit. This has been talked of but experiments of only the most primary character have as yet been made so the idea is in the preliminary stage. To it will doubtless apply the same restrictions as affect the fusion method. It has the advantage that the nature of the deposited metal is more readily controlled than is the case with the others. The cost, however, would probably be against it and outweigh the advantages. It is mentioned here as a possibility.

The local heating of large plates inevitably sets up stresses in the colder parts contiguous to the welds and which must be relieved before being put to use. It is therefore necessary to "stress relieve" the structure when the welding is completed. From the dimensions heretofore given it is evident that a very large heating furnace will be a necessary part of the equipment for any shop which may undertake to make welded drums by whatever method.

How can the soundness of a welded vessel be assured is an inevitable question. It has been asked innumerable times and a satisfactory answer must be given, but about this there are wide differences of opinion. It is, of course, manifestly impossible to investigate every weld by cutting at frequent intervals or by testing to destruction. A non-destructive test that will prove the integrity of the weld with reasonable certainty is re-

quired. It has been proposed and practiced to some extent to vigorously hammer the weld or the immediate vicinity while under a test pressure of twice or more the designed working pressure. Exception has been taken to this practice. There have recently appeared two suggestions for other methods. One is a modification of the Sperry scheme for detecting defective rails. There follows extracts from a paper by Mr. Sperry.

"With the successful application of the electric method of inspection to the examination of rails in track it was but natural that the inspection of welds should be one of the first problems to be considered. The inspection of welding includes not only the location of pockets, cracks, inclusions, overlaps, etc., but also the detection of unwelded surfaces which frequently are held in intimate contact under heavy pressure produced by shrinkage in cooling the weld. The following research item had as its object the investigation of this phase of the problem."

"The faces of two 1-in. steel cubes were so accurately ground, lapped and polished that they fit perfectly over the entire surface, it being possible to lift one cube by its well-known adhesion to the other. The polished surfaces were then carefully washed with ether to remove any trace of grease or dirt. The cubes were now pressed together between two copper outer terminal pads with a pressure of 5000 lb. A current of 100 amperes was passed through the blocks and the average voltage drop noted over unit lengths of the sound metal at different points, then over the same unit length containing the junction of the two blocks. Here were two surfaces as nearly perfect as could be made, pressed together with 5000 lb., yet the electrical resistance of the unit length containing the gap was one hundred seventy-five times the resistance of an equal length of sound metal. This demonstrates that the electrical method is applicable to the detection of any interruption of the molecular continuity of a metal. Many fissures are practically submicroscopic.

"The initial work on the testing of welds by the electric method was performed on welds joining one-half in. cold rolled plates. Both gas and electric welds were tried, each sample containing a hidden defective spot. An adaptation of the standard test method was quickly developed, which made possible the accurate location of the defective spots. This method is not only applicable to welded plates but may be applied to the inspection of welded drums, pipes, etc.

"A plant has been constructed for testing welded joints of plates up to between three and four inches in thickness and forming drums of different diameters. The inspection to date is found to be accurate and dependable. It goes forward at a rapid pace and gives an ink record which is in the nature of a certificate of complete soundness of the weld. This apparatus is capable of adjustment so as to record very minute defects or it will record only those exceeding a certain predetermined area or percentage of a unit length of weld equal to the plate thickness. This widens out the adaptability and usefulness of the method. The circumferential seams are serviced without difficulty, sometimes more easily even than those running longitudinally as they require less length of primary conductor and less flexibility, but this is a minor detail.

"It would thus seem that the time is close at hand, if it has not already arrived, when by a simple combination of a well-known group of scientific facts and elements we are able to ascertain the internal structure throughout any weld or any critical part thereof, thereby finally establishing its complete integrity and freedom from hidden flaws of any type, establishing it as a 100 per cent union throughout its entire extent longitudinally.

"It is believed that electrical inspection should follow closely the welding process, especially on structures, so that if a hidden defect is discovered it can at once be dug out and corrected on the spot, reinspected and the process repeated until a 100 per cent weld is secured. It is hoped that the great ease with which the complete soundness of welds may quickly be tested and a permanent record secured by so simple and straightforward a method will give welding a new impetus, and by

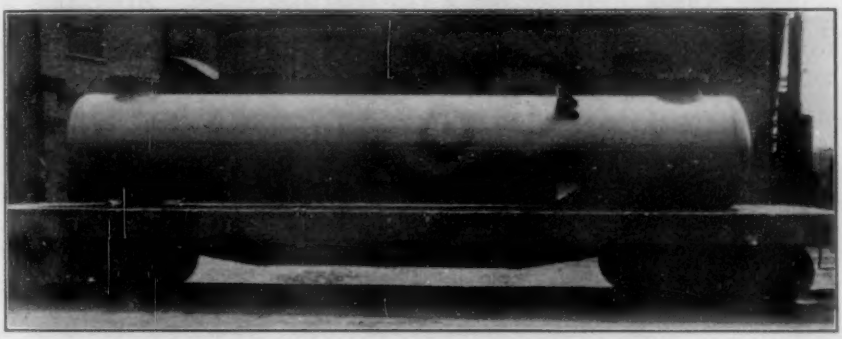


FIG. 6. ARC WELDED VESSEL MATERIAL ¾-IN. SHELL—⅞-IN. HEADS TESTED 200 LB. HYDRAULIC PRESSURE

removing uncertainties will broaden its scope of application and usefulness."

The other method is based on sound transmission by the metal, using an ordinary physician's stethoscope and the X-ray, developed by Kinzel, Burgess and Lytle of the Union Carbon & Carbide Research Laboratory.

"In searching for a non-destructive test of welds the use of sound transmission or sound characteristics of the joint as affected by discontinuities and irregularities was investigated. It is known that the presence of a serious defect in a vessel can often be determined by its ring. The village blacksmith used this principle when he hammered metal cold on the anvil to test it by ring. In sounding a tank, however, there are a great many difficulties to be encountered, due to the forced and natural vibrations of the tank and the tendency for the natural vibration to drown out all other sounds. The authors have used the stethoscope to overcome these difficulties. The instrument consists of the ordinary physician's apparatus, with a gum rubber tip to exclude extraneous sounds and give contact on the irregular surface of the plate, as well as to minimize dampening of the oscillations at the contact of stethoscope and metal. The drum, pipe or plate in question is struck with a small hammer at the spot to be tested. The weight of the hammer

and force of the blow depend upon the thickness of the plate, and the stethoscope is applied to the tank in the general vicinity of the striking zone. The sound heard at the instant of first tapping the joint is critical and is a function of the character of the material at the spot struck. Shortly after the tapping the waves are reflected and the sound picked up by the stethoscope becomes a composite of the natural vibration of the tank as a whole and of the forced vibration of the material immediately under the striking hammer. When the defect is very serious, however, it has a dampening effect on the total sound, so that its presence is also clearly evident in the after ring. The problem is analogous to that encountered in the well established method of testing staybolts by noting the character of the sound on striking. Testing staybolts in this way has proved to be very satisfactory.

"Each welded structure has a characteristic sound. After this is determined by brief preliminary tests the striking hammer and stethoscope are moved along the weld so that any irregularities are discernible."

The nature of the defects located by the stethoscope is of decided interest. Lack of fusion, particularly at the bottom of a vee or along the scarf gives a characteristic reedy, high pitch, initial note. In many instances the points at which welding was started and stopped and where tacks have been made are also discernible with the stethoscope, but the characteristic tone is such that these points are readily different from lack of fusion. To date the authors have been able to check each other in most satisfactory manner in the testing of welded plates, pipes, pressure vessels and welded structural joints.

X-Ray Examination

This method may be used either in conjunction with the stethoscope or as an independent sampling method. In the past most of the X-ray work on welds consisted in taking radiographic pictures through the weld, the X-rays passing in a line normal to the plane of the plate. As a result some idea of the porosity is noted, but the lack of fusion on the scarf in vee welds is not clearly registered on the film. By taking two photographs, one with the X-rays passing parallel to one scarf and one with the X-rays parallel to the other scarf, in addition to the photograph normal to the weld, this difficulty is eliminated. Thus, if there is lack of fusion with or without thorough penetration at the bottom of the vee or along the face of the scarf, X-rays pass along this place unabsorbed and leave their characteristic dark mark on the developed film. From the appearance of the films and a knowledge of the plate metal and welding rod used the ultimate strength of the weld may be estimated with considerable accuracy after a little experience.

A number of welded single V and double V coupons were X-rayed in the manner described, and the ultimate strength estimated from the films. In order to have some poor welds in the series a number were taken from the work of welders who had failed to pass the test required to qualify them for important work under procedure control. The authors had no knowledge of the condition of any particular weld prior to the X-raying.

The coupons were then pulled in the tensile testing machine and the actual strength and the estimated strength compared.

The concordance of estimated and actual strength of the coupons tested is remarkable, and a maximum deviation of 3000 lb. per sq. in. resulted. In a 50,000 lb. per sq. in. weld, this is within 6 per cent of the actual value.

The general plan for a complete method of non-destructive testing of pressure vessels consists in going over the welded joints with the stethoscope and then making X-ray examinations of any points in question.

Conclusions

1. Defects in line welds, girth seams or structural joints may be detected by the use of the stethoscope.

2. A quantitative estimate, good within 3000 lb. per sq. in. of the strength of the weld, can be obtained from X-ray photographs made in accordance with the above-described method.

3. A combination of the use of the stethoscope and X-ray constitutes a satisfactory quantitative non-destructive method of testing welds.

The complete papers describing these methods were presented at the recent fall meeting of the American Welding Society and appear in the September, 1929, number of its journal. These developments are cited to show that some of the uncertainties as to the soundness of welds can be definitely removed and that the problem is well along toward solution. Assurance that a weld is perfect will go far in furthering the willingness of insurance companies and boiler users to accept this method of construction. Both of the methods referred to, as well as the hammer test, are practicable shop operations.

If fusion welded drums are permitted as is quite likely in the not distant future, it will inevitably be under drastic restrictions that will prevent any but adequately equipped shops, both as regards men, methods and machines, from attempting to manufacture by this process. The tentative draft of the regulations now under consideration by the A. S. M. E. Code Committee is of interest. The following are the principal points:

Test plates from which specimens may be cut will have to be welded at the same time and under the same conditions as the shell.

Tension tests must be made which should fail in the plate, but if failure occurs in the weld the stress must not be less than the mean of the range for the plate.

Bend test specimens transverse of the weld must bend cold under free bending conditions until the stretch on the surface is 30 per cent with width of surface cracks deducted, none of which shall be longer than 10 per cent of the width of the specimen.

Impact test specimens from the bottom, middle and top shall have a minimum Charpy value of 20 ft.-lb.

Chemical analysis of weld metal with maximum requirements for manganese, phosphorus, sulphur and iron nitride.

The complete welded structure shall be heated uniformly to certain specified temperatures for different thicknesses, but averaging about 1100 deg. F. and held for one hour per inch of thickness for the purpose of relieving stresses due to welding.

The welded joints shall be explored by means of some form of nondestructive apparatus as will determine quantitatively the size of a defect.

After being stress relieved the vessel shall be subjected to 10,000 applications of hydrostatic pressure varying in a cycle from zero pounds to one and one-half times the working pressure, after which the welds shall again be explored by the nondestructive test apparatus.

Make macro and micro-photographs to show freedom from excessive porosity, incomplete fusion, laps, etc.

No holes shall be located in a weld nor shall a hole be nearer to the edge of the weld than the thickness of the plate with a minimum of 1 in. for plates less than 1 in. thick and 2 in. for plates of that thickness.

When constructed in accordance with the proposed specification the maximum unit working stress may be taken as 16 per cent of the minimum of the specified range for the plate.

It must be understood that these provisions have not been adopted and many of them may be changed or omitted and still others may be added before a final conclusion is reached. It is even possible that there may be enough objection raised so that a code acceptable to all the varied interests concerned cannot at this time be agreed to and that the matter will therefore be more or less indefinitely delayed.

It will be evident from the foregoing that at present, with the exception of forge welding, high pressure boilers may not be made otherwise than riveted or seamless, but that progress is being made and that probably fusion welding will soon receive recognition in the boiler field.

While the A. S. M. E. code does not now sanction the use of fusion welding subject to major stresses, revisions have been made that permit its use in many minor ways, particularly in small firebox types of boilers. In these the bottoms of waterlegs, fire door openings, furnace sheets, etc., may be welded provided the surfaces are adequately supported otherwise. Also attachments of various kinds can be affixed by welding, thus avoiding riveting that not infrequently causes annoyance by leaking besides being cheaper and really better. It will then be seen that the Code Committee has been relenting in its attitude toward welding and is apparently on the verge of a major leap.

At about the point where it is no longer possible to use riveted construction it becomes practicable to use seamless forged drums, the most ideal structure for the purpose that can be imagined but very expensive. We have therefore welded construction in opposition to riveted and seamless for the whole range of thicknesses and the choice will be determined to a great extent if not entirely on the relative costs.

Where conditions are such as not to make welded construction either forged or fusion of paramount importance and first cost is a prime consideration riveted work will continue to be used. Roughly the former

costs from two to three and one-half times that of the latter. That this disparity may in time be lesssened is probable, but just now it is a real factor in making a decision.

The progress of the welding art is so rapid that any developments of the past can be of value only historically. The attempt has been made herein to deal only with the immediate present and imminent future without rehearsing the steps either at home or abroad of the ladder of experiences on which present knowledge and practice has mounted to its present status. It is hoped that what has been said will be of some interest and service to all.

Structural Welding Scores Success on Large Western Project*

By A. W. Lewis†

THE world's heaviest welded truss has just been completed by the Pacific Iron & Steel Company of Los Angeles for the Forest Lawn Memorial Park Mausoleum at Glendale, Cal. It forms a part of an all-welded steel frame mausoleum extending over the top of an existing building. This largest truss is shorter, but heavier, than the 135-foot trusses of the Westinghouse Electric & Manufacturing Company's railroad bridge at Chicopee Falls, Mass., which served as the precedent and guide for the Forest Lawn project.

H. A. Lund of Glendale, former engineer for the owners, designed this structure. According to Gilbert D. Fish, consulting engineer of the Westinghouse Electric & Manufacturing Company, who consulted with Mr. Lund on the design of the welded joints, the use of welding instead of riveting in this structure has made possible a saving of from 12 to 15 per cent in the total quantity of steel employed.

This addition to the Forest Lawn Mausoleum requires carrying very heavy dead loads above the roof of an existing building without support by same. The addition is only one story high, but the 18-ft. height of that story, the 95-ft. length of clear span, and the immense weight of concrete forming the mausoleum cells and encasement of steel framing require heavy steel construction.

The feature of outstanding interest in this project is one of the trusses, 96 ft. long by 18 ft. high, having maximum chord stresses approximating 1,000,000 lb. This is believed to be the greatest load thus far transmitted by any welded joint in a building or bridge frame, and requires the use of gusset plates and slot welds of uncommon dimensions.

Roof trusses of arc welded construction have become fairly common and have generally been constructed without gusset plates. Absence of gussets is a characteristic of light welded trusses and distinguishes them from their riveted counterparts. For trusses carrying heavy loads,

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†Secretary and Treasurer, Pacific Iron & Steel Company.
Cuts loaned through the courtesy of "West Coast Builder."

the overlapping of web members on chord members does not afford sufficient room to permit development of required strength by means of welding along the edges of the web members, and recourse must be had to gusset plates as in riveted construction. Although the general arrangement of members and gusset plates resembles riveted construction, the remarkable concentration of strength afforded by suitably designed welded joints, makes possible the development of the needed strength

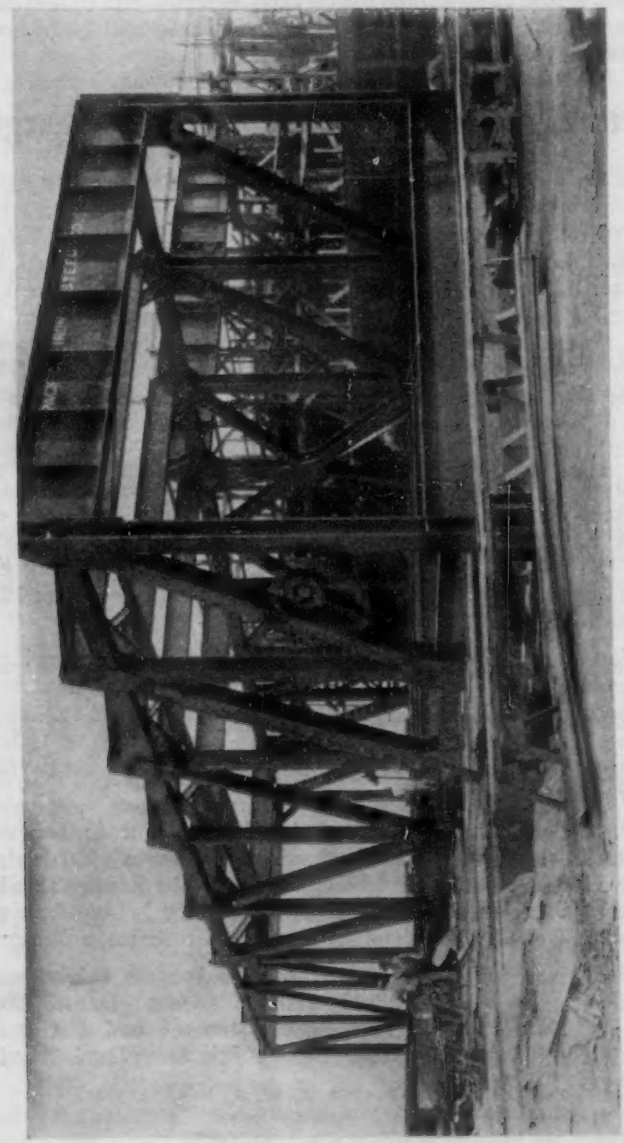

FIG. 1. VIEW OF THE COMPLETED ALL-WELDED STEEL STRUCTURE. LENGTH, 96 FEET; WEIGHT, 123 TONS

within a space much smaller than required for a riveted joint to serve the same purpose. To understand this point, let us consider the maximum strength concentration obtainable under usual specifications in a gusset plate with ⅞-in. rivets. The single shear value of one ⅞-in. rivet, under the specification of the American Institute of Steel Con-

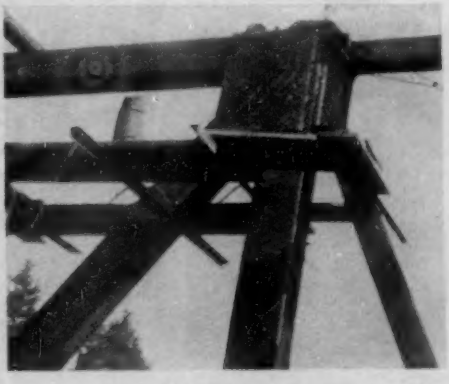

FIG. 2. SCAFFOLDING "TACK-WELDED" ON COLUMNS AND GIRDERS FACILITATES CONSTRUCTION

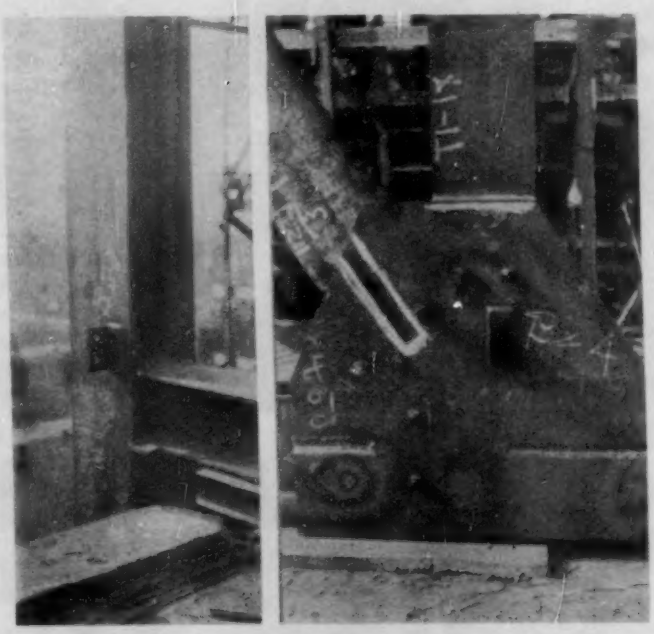

FIG. 3. (LEFT) CONNECTION OF BOTTOM CHORD SHOWING TRUSS CONNECTED TO MAIN COLUMN. FIG. 4. WELDING SLOTS ON GUSSET PLATE, SHOWING BOLTS WHICH ARE RENEWED AFTER WELDING

struction, is 8100 lb. With a staggered arrangement of rivets they may be spaced so as to occupy about 6 sq. in. of plate per rivet, but this is rather too close for first class practice. It will be seen that 1300 lb. per square inch of plate is about the limiting rate of stress transfer with

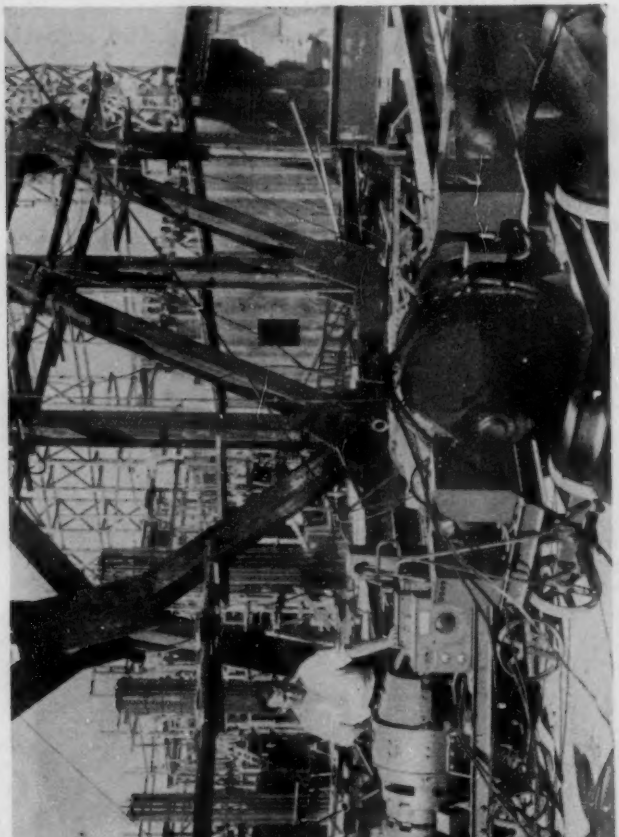

FIG. 6. THREE OF THE FIVE MACHINES USED IN WELDING MAUSOLEUM AT FOREST LAWN

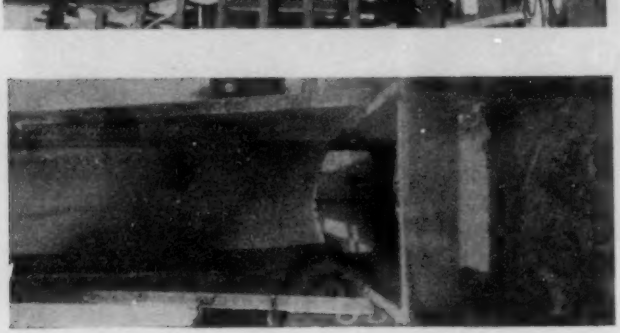

FIG. 5. INSIDE VIEW OF WELDING HEAD JOINING COLUMN AND GUSSET PLATE

the ⅞-in. rivets, and that for conservative practice 1000 lb. per square inch of plate is close to maximum. Slot welds, on the other hand, readily provide far higher rates of stress transfer than the above figures. It is good practice to allow shearing stress of 11,300 lb. per square inch at the bottom of a welded slot, provided the slot width is greater than the depth but not more than twice the depth. (Depth of slot is of course the thickness of the gusset plate.) In the Forest Lawn Mausoleum trusses the slots are 1¼ in. wide by 1 in. deep, the gussets being 1 in. thick. The working stress for these slot welds is 14,000 lb. per linear inch. The minimum permissible spacing of parallel slot welds is governed by their length and the thickness of the gusset plate, because strength of the plate metal between welds is the governing factor. For example, parallel slot welds of the section employed in this job, 8 inches long, may be used to transfer 110,000 lb. each, this stress requiring a strip of gusset plate 1 in. thick by about 6 in. wide in order to avoid excessive tension in the plate material. In the case cited, the slot welds may be spaced about 6 in. on centers and transfers in excess of 2000 lb. per square inch of plate. In other words, strength of the gusset plate is the critical factor in determining rate of stress transfer by means of slot welds. The use of high strength steel for the gussets would permit closer spacing of welds and higher rates of stress transfer without the use of increased working stress in the welds themselves.

The gusset plates of the Forest Lawn trusses have been modeled after those which were employed as an innovation on the Chicopee Falls Railway Bridge of the Westinghouse Electric & Manufacturing Company near Springfield, Mass. That bridge, completed in 1928, established the practicability and economy of slot welded gusset plates in heavy truss construction. The largest of the Forest Lawn trusses, on account of the mass of concrete which it supports, is heavier and requires heavier joints than the Chicopee Falls trusses, which were half again as long and were designed for Cooper's E50 locomotive loading.

Riveted trusses for the Forest Lawn job would have required more steel, mainly for two reasons. The gusset plates, which are a considerable item of weight even in the welded trusses, would have been larger in area and considerably heavier if used for riveted construction. The tension members in case of riveted construction would have been drilled for rivet holes and would have been of considerably greater cross section to allow for the weakening effect of the holes.

While it is not yet universally understood that welded construction of buildings and bridges is as definitely controllable as riveted construction, this is indeed true. Careful inspection should be provided for every important construction operation, whether of timber, reinforced concrete, riveted steel or welded steel. Experienced inspectors of structural welding are able to judge the soundness of welded joints and were employed on this construction.

The growing list of welded structures, which thus far have all been successful, is gradually impressing the minds of the public and of construction men that welding, properly employed, is a means of constructing buildings and bridges safely, quickly and silently.

A Contribution to the Study of Influence of Welding Conditions and Subsequent Heat Treatment on the Structure of the Weld†

By Karl Kuettner* and V. N. Krivobok**, Sc. D.

I. INTRODUCTION

1. Industrial Application of Welding

UNTIL the end of the nineteenth century the only kind of welding known was forging or pressing together of the pieces to be joined. Since then a great many different welding methods have been developed and used with more or less success. In recent years welding has been used so extensively in industry that there is no doubt that in several years it will entirely replace riveting in structural work[1] and shipbuilding[2]. In many cases large castings are being replaced successfully by welded housings. The progress of the welding process is doubtless of the greatest influence in every branch of mechanical, electrical and nearly all other industries. Before entering into discussion of the special problems of the welding process it is desirable to give a careful review of the different kinds of welding and, as far as possible, to study the chemical, physical and metallurgical literature on this subject.

2. The Main Types of Welding

The different types of welding that are used at the present time are so numerous that it seems to be convenient to subdivide their discussion into two main groups. In these groups the welding of cast iron and nonferrous metals, as well as cutting, will not be considered, while the welding of special steels will be only briefly sketched. A subdivision in the discussion of welding (a) below the melting point under pressure and (b) above the melting point, with and without pressure, has been made for the following reasons: the most important of all influences on the mechanical properties of welds is the change in structure from the fibrous rolled structure to the cast structure when the melting point is exceeded; also, in this case, burning of the different alloying elements of the iron is very much greater than in the case where the melting point is not reached. In discussing the chemical and metallurgical conditions of welding, therefore, these two cases will be treated separately.

II. Welding Under Pressure Below the Melting Point

In principle this is the same type of welding that has been used since iron has been known. One of the first commercial applications was the

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†Report presented to the Fundamental Research Committee of the American Bureau of Welding.

[1] For example, *Iron Age*, 115 (1925), p. 1051, gives a general review.

[2] See also, E. H. Ewertz, *Marine Eng. & Ship. Age*, 28 (1923), p. 420 and Strelow, ZS. Ver. dtsch. Ing. 69 (1925), p. 605-606.

welding of tubings. In this process the material is heated to its welding temperature and welding is accomplished by high pressure forcing the two pieces together. Even in a reducing atmosphere it is hardly possible to avoid the occurrence of some formation of oxide or slag films on the surface of the material. It has been observed that wrought iron is very suitable for welding in the production of welded tubes. This is explained by the high slag content of wrought iron. Under the high pressure of the welding operation these oxide films are dissolved in the slag, so that very uniform welds can easily be produced. Very recently a new process[3] was developed for making synthetic wrought iron by mixing an open-hearth steel with especially prepared slag. It is interesting to note that this steel is supposed to have very good welding properties.

It seems advisable to first discuss the limits of weldability as influenced by different alloying elements, which are perhaps more suitably defined as impurities.

Influence of Phosphorus: According to Diegel[4], the limit for soft ingot iron is 0.03 to 0.05 per cent P. Wrought iron, however, does not seem to lose its welding properties up to 0.4 per cent P[5] (high percentage of P is accounted for by the high P content of the slag).

Influence of Sulfur: Diegel gives as limit 0.04 to 0.05 per cent S[6] while higher Mn content (0.5 per cent) makes it possible to weld ingot iron even with 0.125 per cent S[6].

Influence of Arsenic: The results of the different investigators do not quite agree: Harbord and Tucker[7] observed a marked decrease of weldability at 0.1 per cent As; Stead[8] and Liedgens[9] between 0.12 and 0.27 per cent.

Influence of Copper: Up to comparatively high percentages copper has no detrimental effect. Colby[10] and Lipin[11] found the limit at 0.6 per cent. Schulz[12] claims excellent welding properties from chromium-copper steel with up to 0.8 per cent Cu.

Influence of Silicon: Hadfield gives as upper limit 0.2 per cent. Silicon seems to be one of the most undesirable and dangerous elements even in the welding of wrought iron.

Influence of Manganese: Weldability decreased above 1 per cent of Mn[13] and seems to be very good at 0.7 to 0.8 per cent[4].

Influence of Cr, W, Al, etc.: The limit of weldability for Cr is given by Portevin[14] at 0.3 per cent; for W by Hadfield[15] at 0.2 per cent; for Al by

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[3] J. Aston, U. S. Patent 1492412. J. Aston, Trans. Am. Inst. Min. & Met. Eng. (1926), preprint 1595C.
[4] Stahl und Eisen (1909), p. 776.
[5] Ledebur Eisenhütten Kunde III 19.
[6] Harbord & Tucker, Iron Steel Inst. (1886), II 701; 1903 I 136.
[7] Iron Steel Inst. (1888), II 183.
[8] Iron Steel Inst. (1895), I 77.
[9] Stahl u. Eisen (1912), 2109.
[10] Stahl u. Eisen (1900), 54.
[11] Stahl u. Eisen (1900), 540.
[12] Stahl u. Eisen (1928), p. 849-853.
[13] Ledebur. Eisenhüttenkunde. III. 20.
[14] Comptes Rendus (1911), 153. 64.
[15] Iron Steel Inst. (1890), 161.

Hadfield at 0.4 per cent; while data about the other elements are not available.

Influence of Oxygen and Nitrogen: These two gases are of a very great and probably exceedingly detrimental influence on the properties of the weld, but do not influence weldability markedly. Their influence, in regard to welding above the melting point, will be discussed more thoroughly later.

In case the allowed limit of one of the elements discussed above in the steel is exceeded, even excessive pressure or violent forging cannot join the pieces together. The reason for this is probably due to the formation of non-metallic inclusions, iron arsenides, copper sulfides, aluminum oxide, silica[16], and other types of sulfides and phosphides. It is interesting to note that in case of wrought iron the amount of impurities can be much higher and yet the weldability is not affected. The reason for this is probably due to the high solubility power of slag for these impurities. When these slags are absent the impurities cannot be absorbed and welding is impossible. It is also worthy of attention that in case of metals such as Mn, Cu, Si, Al and others, weldability decreases as the tendency to form the corresponding oxides, measured by the heat of formation, increases.

The influence of carbon on weldability has purposely not been mentioned before, since it behaves a little differently from the other elements It is not yet known up to what percentage of C it is possible to weld plain carbon steel in vacuum. The knowledge of this fact would certainly be of considerable theoretical interest, since C is the only element that does not combine with others to form compounds which would affect the weldability. In practical welding processes, however, C combines with the oxygen of the air to form CO_2, so that even in the fastest welding it is difficult to avoid a certain decarburization, which causes quite abrupt change of carbon content in the weld, and often results in diminished strength. In the process of welding below the melting point the dissolving of CO_2 in the steel can probably be neglected. The practical limit of weldability for plain C steels seems to lie around 0.5 per cent C[17].

III. Fusion Welding

A. *Review of the different processes*

1. *Oxyacetylene Welding*[18]*:* This well-known process is based on the burning of acetylene gas by oxygen in a suitable torch:

$$2\ C_2H_2 + 5\ O_2 = 4\ CO_2 + 2\ H_2O \qquad (1)$$

One volume of acetylene requires two and one-half volumes of pure O_2 for complete combustion; the practical ratio, however, is one volume of

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[16] O. Hahn, Dissertation Berlin, 1925. Stahl u. Eisen, p. 7-9.

[17] Mars Spezialstähle, p. 155.

[18] Instruction for Beginners, Journ. Am. Weld. Soc., October, 1927, page 83.

acetylene to from 1.1 to 1.7 volumes of O_2. In reality the combustion takes place in two distinct stages[19].

Stage A: decomposition of C_2H_2:

$$C_2H_2 + O_2 = H_2 + 2CO \quad (2)$$

Stage B: combustion of H_2 and CO:

$$2\ H_2 + O_2 = 2\ H_2O \quad (3)$$

$$2\ CO + O_2 = 2\ CO_2 \quad (4)$$

Much of the oxygen for the Stage B is derived from the atmosphere. Therefore, if excess oxygen is introduced into the flame from the blowpipe, it impinges directly on the metal and causes excessive oxidation. Insufficient oxygen supply, however, causes incomplete combustion of the acetylene and a reducing atmosphere, probably because of the formation of C, according to the equation:

$$C_2H_2 + CO = H_2O + 3\ C \quad (5)$$

In a normal welding operation there are three zones: in the first, the reaction described as Stage A takes place; in third, that of Stage B; while in the second zone, occupying about six times the volume of Zone I, Stage A is completed and Stage B begins. In Zone II, in which all the welding operations are conducted, the temperatures should lie between 2000 deg. and 3000 deg. C[19]. With good apparatus and pure gases temperatures of up to 3000 deg. C. are reached, but do not exceed 3500 deg. (according to C. Bingham[20]). Zone II, according to Booer[21], besides two parts of CO and one part of H_2, contains very small quantities of C_2H_2, O_2, CO_2, and H_2O vapor. In comment upon the widespread and erroneous opinion that the oxyacetylene flame is a reducing flame the statement of Booer is important, that at the temperatures of 2000 deg. to 3000 deg. C. in Zone II the stability of all common oxides becomes so great as to render them unreducible by CO or H_2. The very small amount of oxygen in this zone (around 1 per cent), however, seems to give the zone a slight oxydizing power. The partial pressure of the oxygen is sufficient to cause a diffusion [illegible] very undesirable gas into the weld.

In the oxyacetylene welding process no pressure is applied. Metal from a filler rod is deposited in a V space between the joints to be welded. It can be easily seen that C, Mn and Si, contained in the filler rod and also in the base metal that comes in contact with the weld, must be greatly oxydized and the C content of the weld, therefore, is seldom higher than 0.06 per cent C[22]. It is quite interesting that an increase in the purity of the oxygen influences the efficiency of the process. T. T. Crowe and G. L. Walker[23] mention a saving of 12 per cent in consumption of O_2 by increasing its purity from 99.0 per cent to 99.5 per cent. A mixture of 75 per cent or more H_2 and 5 per cent Hydrocarbons[24], or 75 per cent or more H_2 with a smaller portion of natural gas with up to

[19] T. R. Booer, Chemical Trade Journal, 1924, p. 189-191.

[20] Henning Z. Ver. Dtsch. Ing., 1928, measured as highest temperature 3100 deg. C.

[21] Compare also equation (2).

[22] See also S. W. Miller, Am. Iron and Steel Inst., "Fusion Welding," November, 1921.

[23] Journ. Amer. Weld. Soc., March, 1925, p. 10-21.

[24] U. S. Patent 1551235.

10 per cent CO[25], has also been used. It seems, however, that these processes never attained more than a local importance.

2. *Resistance Welding*[26]: This type of welding differs from arc welding, so far as the heating is concerned, in that the electric current flows between the pieces of metal being welded and these are forced together after reaching a welding heat, which is obtained in several tenths of a second in such processes as resistance, flash, spot and seam welding.

It is pointed out by M. L. Eckman[27] that material should not be heated to the point of melting, thus in this case, the welding really resembles the old blacksmith practice. He gives as the most suitable welding temperature one of 40 deg.-80 deg. C. below the melting point of the steel. If a superheating takes place, which is often the case, the molten material is squeezed out. Since the oxide films and impurities are not always removed in this way, the joints to be welded must have pure surfaces. Non-uniformities in heating make the welding of large sections impossible. For welding wire, rails and smaller sections, however, the process is widely applied[27].

3. *Electric Arc Welding (Metallic and carbon arc)*[28,29]: Conditions in electric arc welding are greatly simplified in comparison with the oxy-acetylene method, since the arc itself is a neutral source of heat[19], both in the metallic and the carbon arc process. While the carbon arc process is used for filling blowholes in castings[29] and a few other purposes, the metallic arc has a wider field of application. In the former process, the arc is supported mostly by the products of combustion of the carbon electrode; while in the latter case, this is done by the vaporizing iron[3] which is immediately oxidized on the outside by the atomized oxygen of the air, so that the arc is enclosed by a tube of pure Fe_2O_3 vapor[21]. The temperatures developed seem to lie around 3500 deg. C. which would cause the filler, one of the electrodes, to melt too rapidly if the current would flow in a different direction, as from the electrode to the welded material. Oxygen and nitrogen as the two main constituents of the air enter the arc, are ionized and either form oxides and nitrides, or are absorbed by the molten steel. These considerations make it quite clear that oxidation in electric welding is greater than that in gas welding.

4. *Arc Welding in a Hydrogen Amosphere:* A process has been developed by Alexander of the General Electric Company, whereby oxidation which, as will be shown later, has great influence on the mechanical properties of the weld, can be avoided. This process consists of an arc enclosed in a stream of molecular hydrogen. A certain formation

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[25] U. S. Patent 1577171.

[26] Journ. Amer. Weld. Soc., September, 1927, p. 120-132.

[27] Welding in the Ford Industries, M. L. Eckman, Journ. Amer. Weld. Soc., May, 1928, p. 31-48.

[28] Trans. Amer. Weld. Soc., December, 1927, 76 pages.

[29] A. Hochstimm, Zs. Ver. Dtsch. Ing. 68 (1924), p. 129-131.

[30] P. Alexander, Journ. Amer. Weld. Soc., June, 1927, p. 62-74.

[31] A. G. Bissel, Aera 13 (1925), January.

of atomic hydrogen in the direct neighborhood of the arc[32] prevents any oxidation, so that high ductility welds are obtained. It is quite important that the voltage drop through the arc be much greater than in the ordinary arc welding process. A greater liberation of energy is the result, which causes a much greater speed of welding. Welding in water gas, methanol and N_2-H_2 mixture[33] has also been conducted successfully and these processes will probably find a wide range of application, since they are cheaper and in the case of liquid methanol, more convenient for transportation than the hydrogen process.

5. *Atomic Hydrogen Process:* Another process designed to overcome the problem of oxidation is the atomic hydrogen process of I. Langmuir. The principle of this process is the fact that the reaction[34]

$$2H = H_2 \qquad \triangle F_o = -75460 \text{ Cal.}$$

is extremely exothermic.

A stream of hydrogen gas passes through an electric arc between two tungsten electrodes and the molecular hydrogen is dissociated to its atomic form, the limit of dissociation being about 0.62. The atomic hydrogen reaches the metal to be welded and liberates a great amount of heat, because of the above reaction and because, with the decreasing temperature, the equilibrium constant is rapidly increasing. The atomic hydrogen process is probably the most interesting combination of the gas and the arc welding methods. Since there is only a limited amount of metallic vapor[35] in the arc between the two tungsten electrodes, a higher voltage drop and, therefore, a greater velocity of welding is obtained. The exceedingly high heat conductivity of atomic hydrogen also greatly assists in the speed of welding. This method entirely eliminates oxidation. Extensive investigations with several other gases, such as mixtures of H_2 and N_2 and ammonia vapor have also been used successfully by Langmuir and Alexander[36]. Since these experiments are by nature similar to the atomic hydrogen method, it will not be necessary to discuss them here, although from the standpoint of an exhaustive study of the welding phenomena, they are of considerable importance.

6. *"Electronic Tornado" Welding*[37]*:* The principle of this process, which is also called the "electric torch" process[38], is as follows: by superimposing a strong magnetic field on the arc flame, its disturbance is avoided. This disturbance, which occurs in the usual electric arc process is originated by the welding current passing through the parts to be welded. The current creates magnetic fields of variable direction, so that the arc has an inclination to wander around, seeking the path of least resistance. This magnetic control gives to the arc a gyratory motion, hence the popular name, "Electronic Tornado." The arc is produced between a copper anode, having a tapered hole in it, and a

[32] P. Alexander, Journal Amer. Weld. Soc., March, 1926, p. 46-55.
[33] Langmuir and Alexander, Journal Amer. Weld. Soc., 1926.
[34] Lewis and Randall, "Thermodynamics," 1923, p. 472.
[35] R. A. Weinman and I. Langmuir, Journ. Amer. Weld. Soc., March, 1926, p. 32-46.
[36] Loc. cit.
[37] Journ. Amer. Weld. Soc., March, 1928, p. 49-52.
[38] J. C. Lincoln, Journ. Amer. Weld. Soc., November, 1926, p. 18-23.

carbon pencil, the cathode, entering this hole. The flame or torch is emitted by this carbon pencil and is probably supported by minute carbon particles[38]. The process has been developed by the Lincoln Electric Company and little is yet known about it. According to A. F. Davis[37], welds obtained in this manner have excellent ductility and the structure is much finer than in the usual electric arc process.

7. *Thermit Welding*[39]: This process is based on the Goldschmidt reaction

$$Fe_2O_3 + 2\ Al = Al_2O_3 + 2\ Fe$$

and is extremely exothermic. The molten iron, resulting from the high liberation of heat is poured into a mould built around the two pieces, which are joined in this way. A large application of this process is in welding of rails.

B. *Metallurgy and Chemistry of Welds*

The various processes of welding having been discussed, it becomes desirable to consider the metallurgy of a weld. One of the first considerations is the change in structure from that of the fibrous rolled structure to the cast structure, which, due to the rapid cooling following welding, is not dendritic. An extremely unfavorable feature of the welding process is that of oxidation, the extent depending upon the type of the process; for instance, the electric arc causes a much greater oxidation than the oxyacetylene process.

In a fast weld, such as welding of wire, oxidation can be limited, but it is not yet known whether it can be completely eliminated. The oxidation of the weld by the extremely active atomic oxygen causes a saturation of the melt with this gas. This probably occurs in two steps; first, by the formation of iron-oxides; second, by their dissolving in the molten steel. These dissolved iron-oxides react with the alloying elements, manganese, silicon, etc., which, however, can be removed also by the direct reaction with the oxygen. It is not possible to give any definite statements concerning the removal of these elements, yet it is known that they are removed to a great extent. The carbon content, for example, decreases approximately 0.03 per cent to 0.04 per cent. According to S. W. Miller[22], silicon and manganese disappear entirely. Sulfur and phosphorus do not seem to be at all affected. With the exception of oxygen and nitrogen (this gas will be discussed later)[40], all other gases that may occur in the arc or in the oxyacetylene torch are also soluble in the molten steel, although their influence on the steel is not so detrimental as is that of oxygen. Hydrogen and carbon-monoxide are probably the most soluble gases in steel[41,42]. It is understood that the solubility of gases in molten metals is a function of their molecular weight and should decrease with their density, yet direct observations fail to show great distinction even between gases of widely different densities, such as argon and helium[41]. At the boiling point, metals are practically free

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[38] Journ. Amer. Weld. Soc., June, 1927, 54 pages.

[40] Page 48.

[41] P. Alexander, Journ. Amer. Weld. Soc., December, 1926, p. 11-14.

[42] Goerens a Paquet determined experimentally that 0.01%-0.2% per weight of H_2+CO+N_2 are soluble in liquid steel. Ferrum 12 (1915), p. 57.

from dissolved gases. With a drop in temperature the solubility at first rapidly increases to a maximum (somewhere between the boiling and the melting point). This is generally the temperature range of the welding process and at this point great gas absorption takes place. With further drop in temperature, solubility slightly decreases and drops abruptly at the melting point. At the place where solidification of the molten metal during the welding process occurs, great liberation of these gases occurs. In welding processes this takes place so rapidly that some gas pockets are undoubtedly formed. It is quite interesting to note that according to Alexander, oxygen has also some valuable influence on solidification. This investigator calls special attention to the fact that the reaction of FeO formation is extremely isothermic. The FeO formed by oxidation of the surface layers partially dissolves in the iron and partially oxidizes to Fe_3O_4[43]. The great heat evolutions cause a rise in the temperature of the surface layers of several hundred deg. C. In this way a slower rate of solidification is obtained and a more complete gas evolution takes place, both being caused by an oxidation process. Alexander observes that the porous electric arc welds obtained in argon atmosphere are favorable evidence of this opinion. A presence of 6 per cent oxygen is sufficient to make the welds more or less free from blowholes.

This conclusion seems doubtful, since argon is an inert gas and, of course, is soluble in liquid steel as a gas and not as a compound. In any case, argon escapes from the melt in solidification causing blowholes. Oxygen, however, is introduced into the molten pool indirectly over the compound FeO; this compound and not the oxygen gas is dissolved into the melt, as has been verified very recently by Herty and Gaines[44]. In solidification the argon gas can escape, but the oxygen can not, so that the existence of blowholes in the one case and their absence in the other is easily explained. Increasing the oxygen content of the argon atmosphere in which the welding is done should theoretically cause saturation with oxygen and limit the absorption of argon to such an extent that in solidification no argon will escape, thus preventing blowholes. In fact, both processes are probably going on simultaneously.

In the atomic hydrogen process the solidifying edge of the molten pool is continuously swept by the atomic hydrogen blown from the arc, thus causing a slow solidification, since H_2 burns to form H_2O with liberation of heat. It is also quite possible that oxygen is extracted from the molten metal by the atomic hydrogen.

It is interesting to note the different opinions that are held concerning the cause of frequent poor ductility of welds. Some people assert that, in addition to the loss of ductility caused by the change from the fibrous rolled structure to the cast structure, the greatest loss can be attributed to inclusions and improper welding. The opinion verified by the extensive experiments of Neese[45] seems, however, to be more conclusive. It

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[43] H. Schenk Arch. Eisenhüttenw. 1 (1927), p. 494, mentions the reaction $4\ FeO = Fe_3O_4 + Fe$, which goes on down to 1100° C.

[44] Amer. Inst. Min. Met. Engrs., March, 1928, Preprint.

[45] Zs. Ver. deutsch. Ing. 68 (1924), p. 1125-1132.

contends that oxygen and, perhaps, nitrogen[46] in solid solution, or in whatever submicroscopic form they may be present in the weld, sufficiently explain the decreasing mechanical properties.

In recent years the question of oxygen in steel has been taken up by many investigators. It is of interest to give a short summary of the results, since they are of value in the considerations of welding. All available data have been utilized by C. Benedicks and H. Löfquist for their recently published iron-oxygen diagram[47]. This diagram shows that not more than 0.05 per cent oxygen is generally soluble in solid steel[48], while, according to several investigations which seem to agree[49], the solubility at the melting point is 0.21 per cent. At higher temperatures the solubility of oxygen in the liquid steel increases and is, for example, according to Herty and Gaines, 0.304 per cent at 1600 deg. C. and 0.452 per cent at 1700 deg. C.[50].

A comparison with some quantitative data about the degree of enrichment of oxygen in the weld, which are given by H. Neese[51] follows:

	O_2 Per Cent	N_2 Per Cent
Electric arc welds:		
Before welding	0.103	0.003–0.005
After welding with a smooth arc	0.243	0.1 –0.13
After welding with a sparking wire	0.318	
Gas welds:		
Before welding	0.11–0.12	0.004–0.006
After welding	0.13–0.15	0.016–0.017

These data indicate that the enrichment in gases is much greater in the electric arc processes than in oxyacetylene welding, and the oxygen content is even higher than the solubility of oxygen at the melting point. This means that the evolution of the oxygen from the molten pool (as far as the gas exceeds the saturation limits) is supressed by the very fast cooling of the metal.

It might be mentioned that the methods of oxygen determination in steel are not yet definitely standardized so that data obtained by the old Ledebur method, the modified Ledebur method and the recently developed methods of extraction at 1600 deg. C. sometimes give widely varying results, which prevent drawing dependable conclusions.

While most investigators agree that a great part of the detrimental influence of gases on the properties of the weld is due to oxygen and that the influence of hydrogen is very small, opinions about the effect of nitrogen differ slightly. It is well known that nitrogen forms a very brittle nitride with iron and that it can furnish an extremely hard surface if introduced into the steel under special conditions[52]. This

[46] Influence of nitrogen, see page 48.

[47] Zs. Ver. deutsch. Ing. 71 (1927), 1576; Z. anorg. u. allg. Chemie. 171 (1928), p. 231.

[48] The extensive researches of R. Schenk (Z. anorg. Chemie 166 (1927), giving a solubility of 2%-3% are not considered here.

[49] Hanson a. Tritton, Journal Iron Steel Inst. 110 (1924), p. 90.

[50] Herty and Gaines, Amer. Inst. Min. Met. Engr. (1928), March preprint.

[51] Z. Verein Deutsch Ing. 68 (1924), p. 1125-32.

[52] A. Frey Krupp, Monatsh 5 (1924), December, p. 266-269.

would indicate that even very small amounts of nitrogen have some effect on the ductility of steel. Experiments conducted during the development of both hydrogen processes[53] proved that only nitrogen contents of more than 0.05 per cent markedly effect the mechanical properties of steel. The presence of 0.1 per cent N_2 in the steel causes a decrease in ductility to zero according to H. Neese.[54] If we compare these two facts with the nitrogen data given in the table on page 48, it can be seen that the dangerous limit of nitrogen content is greatly exceeded, for there is sufficient nitrogen in the weld to cause a drop of the ductility to zero. It is, of course, obvious that commercial welds prepared with a smooth arc cannot be completely lacking in ductility. For this reason it is probable that the limited data concerning the mechanical properties of welds are not entirely reliable, and in this particular case it is quite useless to compare the data of different investigators.

So far as the two processes of the General Electric Company are concerned, it is of interest to mention that they were originally developed as pure hydrogen processes in order to avoid any introduction of oxygen or nitrogen into the weld. Later experiments were extended to mixtures of hydrogen and nitrogen and welds made with a gas of up to 92 per cent N_2 proved very ductile and satisfactory. Microscopic examination showed the same number of nitride needles in the gaseous shield welds and atomic gas welds as in the usual electric arc welds. This fact would suggest that nitrogen has no influence on the mechanical properties of welds.

Comparing the data of the oxygen influence on the mechanical properties (given later) with the quite incomplete data about the influence of nitrogen, it can be summarized into the conclusion that both gases have a detrimental influence on the mechanical properties of the weld. It must be remembered, however, that other variables may exist, which as yet are unknown, but may be of importance.

C. *Metallography and Heat Treatment of Welds*

Some work on the metallography and heat treatment of welds has been done in the last decade. Impurities play the main rôle here, just as in the discussion of the welding itself. They are present in the weld to a much greater extent than in pure open-hearth steel. Since the weld cannot be deoxidized in any manner, the impurities cannot flow out on the surface, as in the case of slag, and sometimes fail even to combine in larger particles; they are rejected to the grain boundaries, where they solidify. According to S. W. Miller[54], ruptures never occur along the alpha grain boundaries, since they are formed by the recrystallization of the gamma grains. In cases of welds containing much pearlite, where it is possible to distinguish between the alpha and gamma grain boundaries, this investigator observed that ruptures occur only along the austenite grain boundaries. The impurities, which in this way cause intercrystalline fractures are not

[53] Loc. cit. papers of Langmuir, Alexander, etc.

[54] Amer. Iron and Steel Inst., December, 1921.

visible under the microscope and their presence can be detected only by grain-growth experiments. Whether the lack of uniform recrystallization is due to oxide films or to the presence of oxygen dissolved in the steel and enriched on the outside of the gamma grains, cannot be definitely stated at the present time. Under certain circumstances these impurities may, however, combine into larger units.

Failures in the weld are caused more often by poor welding, where no union of the base metal and the deposited metal is obtained. These faults can be avoided to a great extent, however, since they are chiefly dependent on the skill of the operator and the perfection of the apparatus.

S. W. Miller, in his quite extensive report about the metallography of welds, mentions the very important fact that he never observed any fractures along the nitride needles[55]. This seems to disprove the opinion that nitrogen exerts a detrimental influence. It is, however, not yet known to what extent nitrogen might be present in solid solution[56].

In practically every type of welding certain quenching phenomena are observed which are due, of course, to the very fast cooling. This fact has no great detrimental influence, since in most cases low-carbon materials are used in commercial welding. Higher carbon materials, however, must be heat treated after welding in a suitable way, if possible. Since there are always two types of structure in welds, the cast and the rolled, two subsequent heat treatments should be used: the first at 1750 deg. F. to refine the distorted grains of the cast section, the second at 1450 deg. F. to refine the coarsened base metal, which, however, is not always commercially possible[57].

In a cross section through a weld from the center to either side the following structures can usually be seen:

(1) The cast structure of the weld.

(2) The superheated, but still unmolten grains bordering the weld which decrease in size with distance from the weld. The grains bordering the weld are sometimes martensitic, when the steels have higher carbon contents.

(3) Another increase in the grain size, due to the critical range of recrystallization after cold-working.

(4) Normal structure of the base metal, showing slightly elongated alpha crystals.

An interesting phenomenon sometimes observed in welds is that of the appearance of large, bright, shining areas, so-called flakes, which can be observed on the unetched sample. Whiteley[58] explains this by the presence of FeO, dissolved in the steel.

Heat treatment of welds in structural work, shipbuilding and other industries has not, up to date, been applied on a large scale. In welding

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[55] Compare pages 48 and 49.

[56] Loc. cit.

[57] J. R. Dawson, Amer. Soc. St. Treat. (1923), p. 467-487.

[58] British Iron and Steel Institute, 1921.

of pipe lines, however, heat treatment plays an important and quite successful part. It is conceded that it is good practice to deposit the metal in several layers, since in this way heat treatment is given to the layers deposited before. As can be expected, a certain recrystallization takes place, removing strains and a part of the grain distortion[60].

The definite limits of weldability in fusion welding, as influenced by alloying elements, cannot be given, since they lie at very much higher concentrations than welders confront in practice. In the important process of resistance welding, however, conditions are different. This process is, as has been mentioned, an intermediate type between the two main types of welding. For this process P. Hahn[61] gives the following weldability limits for the elements forming solid solutions with the iron:

As up to 0.6%	Al up to 0.3%
Cu up to 0.8%	Si up to 0.35%
Mn up to 1.0%	

The only fusion welding processes which allow higher carbon contents are those of the resistance welding type, for here the carbon cannot burn out, because of the very rapid welding.

A brief mention might be made of the most suitable etching reagents for welds.

A. *Low-Carbon Materials:*

1. Copper ammonia chloride reagent of Heyn.
2. Copper chloride reagents of Le Chatelier.
3. Ammonia persulfate (1:10). This reagent is superior to the others, according to E. Jimeno and C. del Fresno[62], especially in the investigation of rail joints.
4. The 10 per cent HCl, 30 per cent H_2SO_4, 60 per cent H_2O reagent, and
5. The 25 per cent HNO_3, 65 per cent H_2O reagent, both recommended by Sauveur[63].

B. *Materials with more than* 0.3 *per cent carbon:*

The $CuCl_2$, $SnCl_2$, $FeCl_3$ reagent of Oberhoffer[64].

In the case of Oberhoffer's reagent, the phosphorus segregations remain bright and the base becomes a dark brown color, contrary to the behavior of steel etched by the reagents of Heyn and Le Chatelier.

In addition to these macroscopic etchants, various microscopic reagents may be applied, if a more detailed examination of the weld is desired.

C. *Mechanical Properties and Testing of Welds*

It has been mentioned before that the mechanical properties are influenced chiefly by two factors: (1) by change from the fibrous rolled

[60] A. G. Bissel, Westinghouse Welding Paper.
[61] Stahl und Eisen, 1925, p. 7-9.
[62] Annals Soc. Espanola Fis. Quin. 22 (1924), p. 245-255.
[63] Metallography (1926), p. 507.
[64] Stahl und Eisen (1916), p. 798.

structure to the cast structure, and (2) by the incomplete or total lack of degasification of the weld.

The tensile strength of the material in the weld is either unchanged or even raised; this has been widely observed[65] and is probably due partly to the hardening by the dissolved oxygen and other gases and partly to the fast cooling and considerable grain distortion. Ductility drops markedly, shown by an increasing brittleness, which causes the decrease of elongation, contraction in area, and impact resistivity[65]. Especially marked is the drop of the impact resistivity in welds and, therefore, an impact test seems to be of the greatest value in the testing of welds. Because of the different absorption of gases and rate of cooling in electric arc and oxyacetylene welds the mechanical properties also can change in wide limits. For example, in oxyacetylene welding better values of the cold bend test[66] are obtained. How dangerous nitrogen in higher concentrations might be shown by Neese[67] quantitatively: 0.1 per cent nitrogen causes an increase of the tensile strength of 20 per cent and a drop of the elongation to zero. R. R. Moore[68] made an interesting study of the fatigue of welds. Although the tensile efficiency of the welded tubes was better than 75 per cent, the fatigue strength was as low as 13 per cent and never higher than 35 per cent of the tensile strength of the weld. Poor fusion has a drastic effect upon the resistance of the weld to repeated stresses and may be detected by the fatigue test, but not by the tensile test. (Compare also: "Fatigue of Welds by Vibration.")[69] Elevated temperature tests of welds furnished the following results:[70] as far as tensile strength is concerned, a strong weld cold is generally also a strong weld hot. This is not as consistently true of the proportional limit figures. The continuation of this investigation has not yet been published. Pomp[71] mentions an extreme drop of the impact resistance below 0 °C. The heat treatment of welds does not seem to change the tensile strength, but markedly improves ductility[57].

An entire change of the mechanical properties of welds has been obtained by the atomic hydrogen and the gaseous shielded process. According to the investigations of Alexander, Langmuir, Weinman and others[72], excellent ductility is obtained in this way, while no lowering of the impact resistance is observed. Also, an exceptionally high elastic limit is obtained, which is supposed to be due to the washing of the metal with atomic hydrogen.

The most common practical methods for testing welds are: 1. The *cold bend test*, which is well known and applied in smaller joints. Here we make a distinction between samples as furnished and samples in which

[65] For example: S. W. Miller, Amer. Iron and Steel Inst. (1921), November; W. Hofmann, Werkstattechnik (1926), No. 3; Mies, Die Schmelzschweissung (1925), p. 83.

[66] Diegel, Stahl und Eisen (1922), p. 1309.

[67] Z. Vereins Dtsch. Ing. (1924), p. 1125-1132.

[68] R. R. Moore, Journ. Amer. Weld. Soc. (1927), April, p. 11-32.

[69] Mechanical Engineering (1925), p. 794.

[70] K. V. Laird, Ch. Moser, Journ. Amer. Weld. Soc. (1927), September, p. 30-45 (Prelim. Report).

[71] A. Pomp, Stahl und Eisen (1927), p. 2187.

[72] Loc. cit.

the excess metal has been removed by grinding to the diameter of the welded parts.[73]

2. The *penetration test*, which is used for testing high-pressure vessels, which are filled with hydrogen, air, or kerosene, while subjected to pressures considerably in excess of the operating pressure. This test is sometimes called hammer test, because the vessel is often tested by striking vigorously with a hammer to detect a poorly welded place.[74,75]

In the last few years several attempts have been made to test welds by X-rays and by magnetic methods. It seems, however, that the X-ray method reveals only gas pockets, oxide inclusions and cracks, but that with the present methods there is little if any detection of poor fusion[74,75,76].

Still less is known about magnetic analysis, which, so far as welds are concerned, is not out of the laboratory stage. In 1926 the results obtained in this field by S. W. Miller[77] were discouraging. Since then there has been, however, considerable progressive work.

To a certain extent the abnormality of carburized welds belongs in this chapter also. Weber[78] was able to show that all curburized welds were abnormal with the exception of those which had been welded in helium atmosphere. Whether this abnormality is caused by oxygen and nitrogen is not known, but it is quite possible.

Data about the influence of the oxygen content on the properties of steel are contained in the recent Carnegie Institute of Technology Bulletin No. 24.[79] They show an ultimate strength equal to and above that of pure iron. The drop of elongation, however, is quite marked, being 40 per cent, 36 per cent, and 33 per cent at 0.2 per cent, 0.25 per cent and 0.35 per cent oxygen as compared with around 45 per cent of pure iron.

E. Welding Special Steels

It has been mentioned before that definite limits of weldability do not exist in the case of fusion welding, so that nearly any two metals can be melted together. The changes in structure and in mechanical properties, however are often so great that many unsolved difficulties exist in welding special steels. This is pointed out by J. R. Dawson,[81] G. L. Walker,[80] and S. W. Miller,[77] for high carbon, high speed and high manganese steels and by C. J. Holslag,[82] for the stainless steels. A. W. Harris describes a "stelliting" process where stellite is deposited in the molten state on

[73] Fuechsel, Stahl und Eisen 45 (1925), p. 199.

[74] P. W. Swain, Journ. Amer. Weld. Soc. (1926), June, p. 50-59.

[75] O. H. Eschholz, Journ. Amer. Weld. Soc. (1925), April, p. 55-58.

[76] J. P. Norton, *Iron Age* (1926), Vol. 118, p. 409-412.

[77] Journ. Amer. Weld. Soc. (1926), May, p. 17-19.

[78] Amer. Soc. Steel Treat. (1926), Chicago, Sept., p. 20-24.

[79] Solubility of FeO in iron, The Phys. Chem. of Steel Making, No. 24, p. 59.

[80] "Welding High Carbon Tool Steel and High Speed Steel with the Oxyacetylene Torch," Journ. Amer. Weld. Soc. (1926), July, p. 40-48.

[81] "Electric Welding the New Stainless Steels," Journ. Amer. Weld. Soc. (1926) p. 47-60.

[82] "Welding of Manganese Steel," Acetylene Journal (1924), p. 65-71.

[83] Journ. Amer. Weld. Soc. (1927), January, p. 14-17.

some other type of steel. R. A. Weinman[54] mentions similar processes, chromizing and calorizing. In these two methods of deposition of metals, however, the atomic hydrogen and shielded arc hydrogen torch are used. Both methods seem of great importance in relation to future development, since all experiments up to the present time, with nearly all types of special steels, have been quite successful.

IV. Filler Rods, Fluxes, Coatings

These all play an important role in the welding process. Especially is the question of filler rods an important and, as yet, an unsolved one. It is pointed out by C. A. McCune[55] that it is nearly impossible to obtain a rod of an exact constant composition, because of the segregations in the ingot. A very thorough investigation of H. Neese[51] showed that the carbon content alone is not the cause of occasional marked sparking of the rod in the arc, since often very low carbon materials are thus characterized. The sparking causes considerably higher oxygen content.[56] Again, the gas content of the rod does not seem to be the only reason for this sparking, as pointed out by the same investigator, who could obtain no better results with vacuum molten rods than with those prepared in an oxydizing or reducing atmosphere. Neese recommends testing every heat, or even every ingot, which is to be rolled down to be used as welding wire. In certain contradiction to the above experiments are the results from the well-known and widely applied flame test:[57] in melting down the surface of wire with a small oxyacetylene flame, the metal in unsuitable wire boils with a disturbing action, and the metal in a satisfactory wire melts quietly and smoothly, without any evidence of gases or other inclusions. Even if the work of Neese makes it doubtful whether gases alone have a detrimental influence on the welding rod, the flame test is admittedly the most reliable method of examining welding rods.[58]

Another point on which opinions widely differ is that of whether hard-drawn wire must be used. S. W. Miller states that this is necessary in the case of electric arc welding and of no importance in the oxyacetylene process. The reason for this fact is unknown. A contrary opinion is expressed by Neese,[51] who states that any question of using hard-drawn or tempered wire never should have arisen, since it is not of importance.

In Table III, several types of filler rods are given, which have been used according to different articles published in the Journal of the American Welding Society, 1923-1928. The alloyed filler rods have generally been tested out (1) to prevent as far as possible any introduction of oxygen and nitrogen, or the usual gases into the weld, and (2) to give a greater strength to the joints. L. J. Jones and W. S. Weeks[59]

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[54] Journ. Amer. Weld. Soc. (1926), October, p. 69-76.

[55] Journ. Amer. Weld. Soc. (1927), June, p. 39-45.

[56] Compare table, page 48.

[57] See for example: C. A. McCune, Journ. Amer. Weld. Soc. (1928), January, p. 46-47.

[58] Compare also: E. E. Thum, Journal. Amer. Weld. Soc. (1927), May, p. 38-43; McCune, Journ. Amer. Weld. Soc. (1927), May, p. 44-51; McCune, Journ. Amer. Weld. Soc. (1925), October, p. 32-36.

[59] Journ. Amer. Weld. Soc. (1927), June, p. 6-26.

mention a low-carbon-molybdenum welding rod being used successfully in welding of a pipe line. In the discussion of Jones and Weeks' paper,

TABLE III

Showing some compositions of welding rods

Name	Especially for:	Chemical Composition		
1. Low carbon wire[90]	Gas welding	0.06% C	0.15% Mn	
2. Low carbon wire	Electric welding	0.15	0.5	
3. V steel filler rod[90]		0.25	0.43	0.15% V
4. Cr-Mo steel filler rod[91]		0.28	0.61	0.95% Mo 1.14% Cr
5. Ni steel filler rod[92, 93]		0.2	0.4–0.6	3.25–3.75% Ni

S. W. Miller reports very poor results obtained with 0.06 per cent carbon, 0.15 per cent vanadium rods. J. B. Johnson[94] discusses welding of aircraft members of the following composition, which are subjected to severe stresses: 0.25-0.35 per cent carbon, 0.4-0.6 per cent manganese, 0.8-1.1 per cent chromium, 0.15-0.25 per cent molybdenum. Welding rod of 0.08 per cent carbon (maximum), 0.15-0.35 per cent manganese was used successfully in this case. A chrome-molybdenum wire had no special advantage. A nickel steel wire of 3.5 per cent nickel, however, was successfully applied. Nickel steel seems really to give the best results of all alloyed steels. W. Hoffmann[94, 92, 95, 96] explains this by the great resistivity of nickel alloyed materials to the absorption of gases, especially of nitrogen. The analysis shows an increase of nitrogen only from 0.011 per cent to 0.012 per cent. S. W. Miller thinks that this resistivity to absorption of gases is due to the formation of a viscous nickel oxide slag.

Coatings for electrodes consist of paper, asbestos and many other materials.[95] They act first as mechanical shrouds and later, after melting, as fluxes. It is quite doubtful whether their use is beneficial in the general commercial processes. This is especially true in the electric arc process, since the solidification of the molten pool takes place so fast that these fluxes which are dissolved to a certain extent cannot flow out on the surface. Advantages in the use of fluxes, especially in the oxyacetylene weldings do exist. The fluid slag favors the flowing up of impurities and does not show a tendency to surround the iron crystals by oxide films. Later, a part of this slag coating vaporizes and gives to the arc a greater stability. Coatings are of greater importance in the welding or deposition of special steels. C. J. Holslag [96] points out that recent developments of the coating practice make it possible to deposit metal of a predetermined composition, for instance, high carbon steel, manganese steel, etc.

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[89] Journ. Amer. Weld. Soc. (1927), June, p. 6-26.

[90] J. R. Dawson, Amer. Soc. Steel Treat. (1923), p. 467-487.

[91] S. T. Sisco and H. W. Boulton, Acetylene Journ. (1926), p. 377-383, 410-414.

[92] S. W. Miller, Amer. Iron and Steel Inst. (1921), November.

[93] W. Hoffmann, Werkstattechnik (1926), 3, p. 74-76.

[94] Acetylene Journ. 27 (1925), p. 278-286.

[95] Compare also: J. R. Booer, Chem. Trade Journ. (1924).

[96] Journ. Amer. Weld. Soc. (1924), January, p. 21-24.

V. Description of Experimental Results Obtained in Resistance Welded Low-Carbon Steel Wire.

The wire was welded on a special resistance welding machine in the plant of the American Chain Co. in Bridgeport, Conn. In order to judge to what extent the ability of the different welders influences the quality of welds, all the welding was done by two different men, who will be called I and II. The time of welding changed from 0.4-0.6 seconds each.

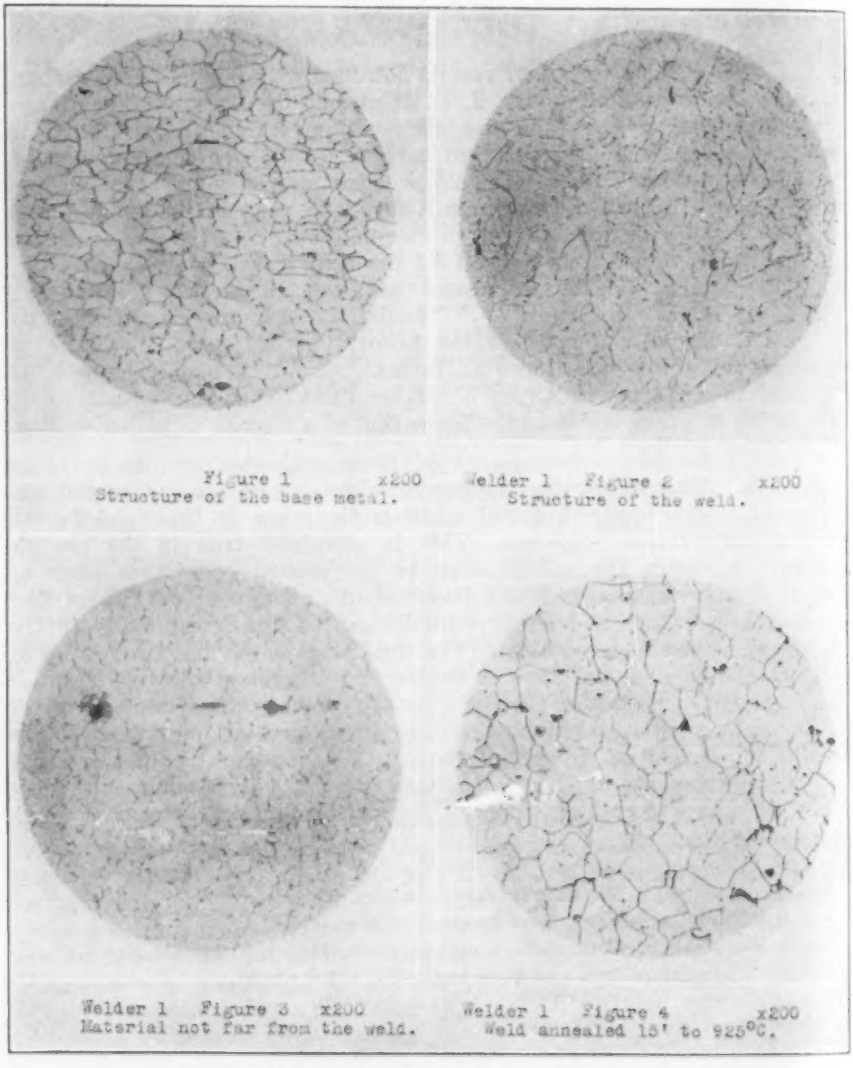


Figure 1 x200
Structure of the base metal.

Welder 1 Figure 2 x200
Structure of the weld.

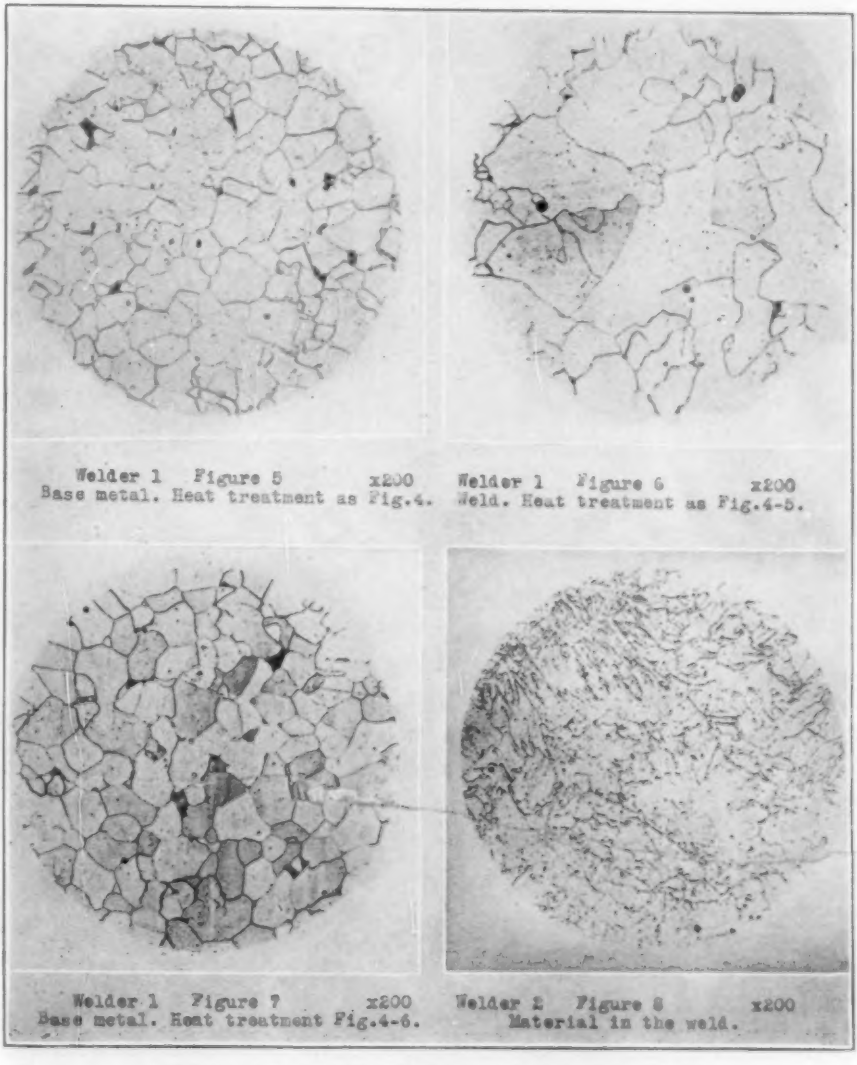
Welder 1 Figure 3 x200
Material not far from the weld.

Welder 1 Figure 4 x200
Weld annealed 15' to 925°C.

Photomicrographs Reduced to About ½ Original Size

Fig. 1 shows the structure of the wire. The material has a very low-carbon content and the grains are elongated slightly in the direction of rolling.

Fig. 2 shows the weld with the typical distorted structure. Fig. 8 represents another weld prepared by a different welder. It is important to note that the weld itself is not seen, as is often the case in welds done by deposition of metal. The structure shows a continuity from the distorted structure to the very uniform structure in that region where the



Welder 1 Figure 5 x200
Base metal. Heat treatment as Fig.4.

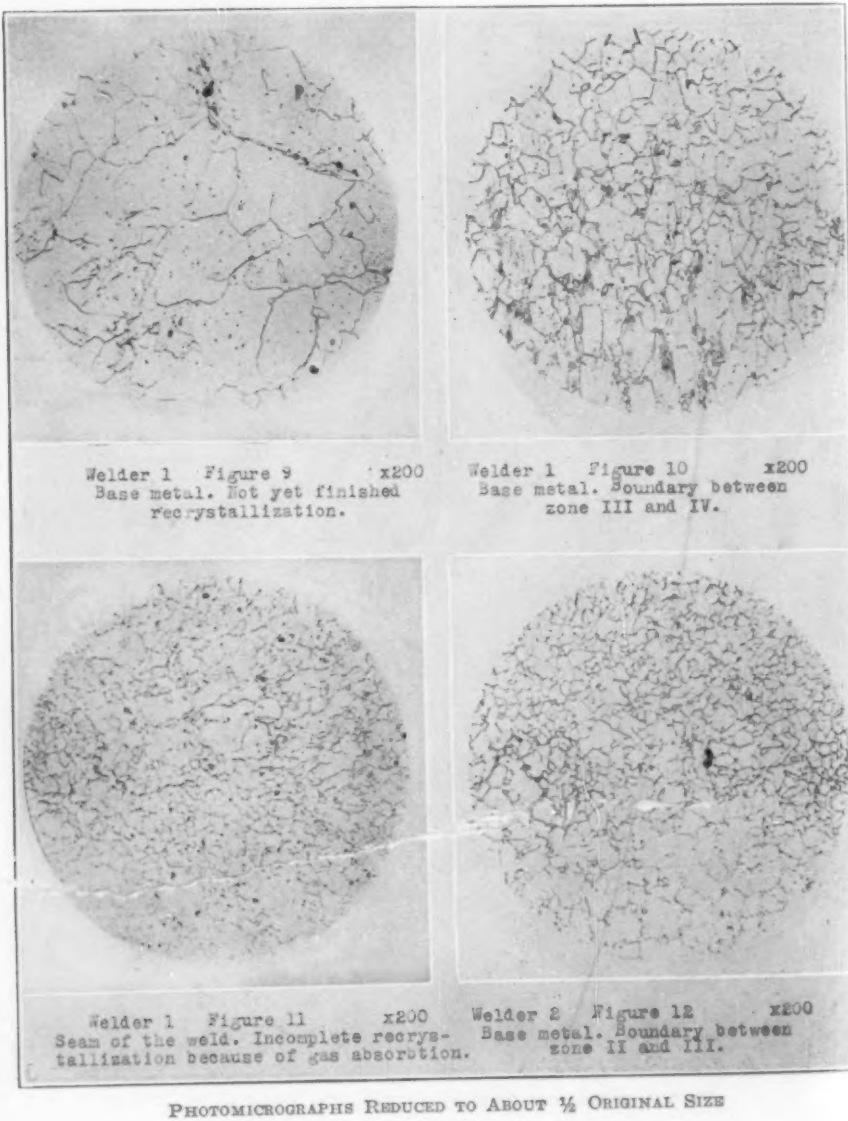
Welder 1 Figure 6 x200
Weld. Heat treatment as Fig.4-5.

Welder 1 Figure 7 x200
Base metal. Heat treatment Fig.4-6.

Welder 1 Figure 8 x200
Material in the weld.

PHOTOMICROGRAPHS REDUCED TO ABOUT ½ ORIGINAL SIZE

metal melted. The directional arrangement disappears, because of the short anneal by the welding operation, as can be seen from Fig. 3. The direction of rolling is marked by the inclusions. From the weld to the outside the grain size decreases quite uniformly. This is because the temperature to which the wire was annealed varied with varying distance from the middle of the weld. If the degree of deformation of the wire were known, it would be possible to determine what temperatures had been reached at the different distances from the center of the weld,



Welder 1 Figure 9 x200
Base metal. Not yet finished recrystallization.

Welder 1 Figure 10 x200
Base metal. Boundary between zone III and IV.

Welder 1 Figure 11 x200
Seam of the weld. Incomplete recrystallization because of gas absorption.

Welder 2 Figure 12 x200
Base metal. Boundary between zone II and III.

PHOTOMICROGRAPHS REDUCED TO ABOUT ½ ORIGINAL SIZE

using the recrystallization diagram.[97] The picture thus obtained would, of course, be qualitative only, since the materials are not exactly the same and the time of annealing in this particular case is quite short.

As discussed in III, B and C, the gases introduced into the weld are probably the principal cause of poor mechanical properties. Whether they are present in solid solution or as compounds, or in both states, is

[97] Oberhoffer a. Jungbluth, Stahl und Eisen (1922), p. 1513.

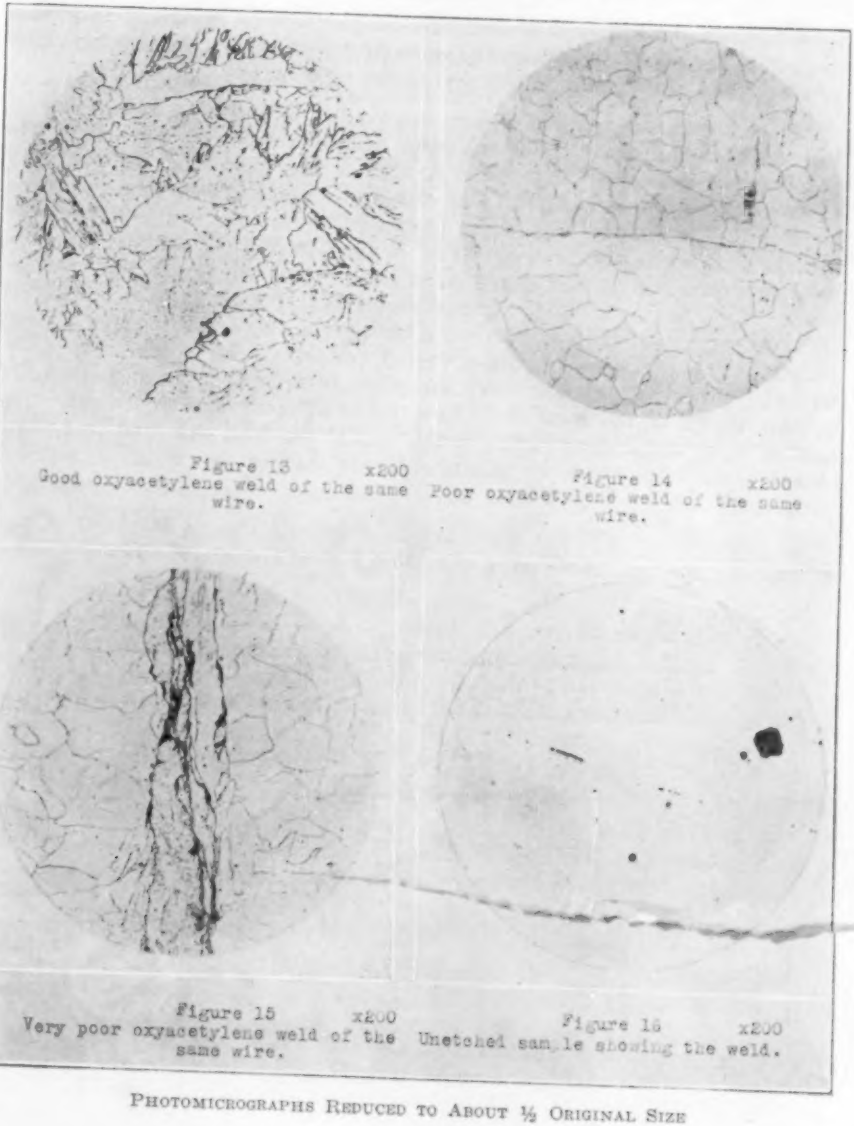


Figure 13 x200
Good oxyacetylene weld of the same wire.

Figure 14 x200
Poor oxyacetylene weld of the same wire.

Figure 15 x200
Very poor oxyacetylene weld of the same wire.

Figure 16 x200
Unetched sample showing the weld.

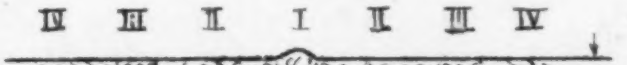
PHOTOMICROGRAPHS REDUCED TO ABOUT ½ ORIGINAL SIZE

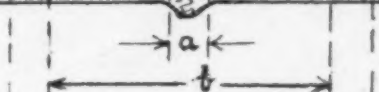
not yet definitely known. In any case, it is quite probable that recrystallization is detrimentally influenced by them. It is therefore possible to estimate within certain limits the properties and quality of the weld from the amount of recrystallization. The recrystallization which takes place below the critical point may be influenced by small amounts of dissolved gases, which do not influence the mechanical properties of the weld. If, however, recrystallization cannot take place even above the critical point, we may be sure that considerable amounts of gases are present and the mechanical properties will be quite poor.

In the following it will be desirable to discover by means of recrystalliation experiments whether the absorption of gases has really been avoided to a very great extent by rapid welding.

Fig. 4 shows the weld of a wire heated for 15 minutes to 925 deg. C. Fig. 5 shows the structure of the same sample away from the weld. The pictures show exactly the same structure, the distortion of the weld having entirely disappeared. The same observation was made in three other welds treated in this way. In one of these four samples, however, no recrystallization was observed as is seen in Fig. 6. Away from the weld recrystallization had taken place in the same way as in the previous cases. This can be seen by comparison of Fig. 7 with Figs. 4 and 5. In these experiments the samples were partly cooled in the furnace, partly in air. The influence of these varied conditions is, however, not apparent. Since all samples were annealed in vacuo, no influence on the outside layers of the weld could have resulted from this treatment. The lack of recrystallization in the seam, which could be observed in several cases is due, therefore, to gas absorption during the welding process. (Fig. 11.)

As discussed previously, there are four definite ranges in the structure of welded material. Following is a table giving the length of each range:





TABLE

Welder	Wire Diam.	a	b	c
I	5 mm.	5 mm.	20 mm.	29 mm.
I	5 mm.	8 mm.	17 mm.	20 mm.
II	5 mm.	8 mm.	15 mm.	17 mm.
II	5 mm.	6 mm.	20 mm.	26 mm.

Fig. 9 is typical for unfinished recrystallization and is taken from a place near the boundary of Zone II and III. Fig. 10 shows the boundary of Zone III and IV; Fig. 12, the boundary of Zone II and Zone III.

The advantage of these resistance welds, as compared with oxy-acetylene welds, lies not only in the comparatively short time required for welding but also in the superior quality of the weld itself, as can be observed by a comparison of these welds with some gas welds shown in Figs. 13, 14 and 15. The length of the regions influenced by the welding operation increases from maximum 29 mm. in the resistance welds to 40 mm. and more in oxyacetylene welds, which were also prepared by expert welders.

VI. Description of Experimental Results Obtained in Resistance Welding of Commercial Low-Manganese-High-Carbon Wire.

(0.73 per cent carbon, 0.51 per cent manganese)

The wire, which was given a special heat treatment as a whole after the welding was done, was furnished without having been heat treated. In spite of the fact that the weld has very good properties, small inclusions in the seam are noticeable both in the unetched sample, Fig. 16, and in the etched sample, Fig. 17. A macroscopic examination of the weld shows that a narrow strip on both sides of the weld is less attacked by the etching reagent than any of the other material. The generally accepted time of etching with nitric acid, which for low carbon material is between 20 and 30 seconds, is but a few seconds for steel with higher carbon and manganese content. Since in the case of this particular steel wire the etching time drops to two to three seconds, it is obvious that the weaker etching is due to a lowering of the carbon content and possibly the manganese content also, in the layers directly around the well.

The small inclusions that are seen in the weld are, therefore, probably iron and manganese oxides. The thickness of the decarburized section varies from 0.1 mm. to 0.3 mm. Due to the influence of the welding heat, there is a corresponding decrease of the grain size, which cannot be observed as plainly as in the low-carbon material, because of the perlito-sorbitic structure. Fig. 18 shows the normal structure of the wire away from the influence of the welding operation. Figs. 19 and 20 show the material outside and in the weld after annealing fifteen minutes to 950 deg. C. and slow furnace cooling. While in the first photo-micrograph, the unhindered grain growth is observed, in Fig. 20, the weld could not be removed entirely, probably because of the presence of oxide films. In the center of the picture, however, the grains could grow through the weld.

Several drawing experiments with this wire will not be discussed here, since they are not directly related to the examination of the welds.

VII. Summary

1. As complete a study of the metallurgical literature of the welding processes is given as was possible to accomplish in the available time.[28]

2. In the study of resistance welds of low carbon wire, recrystallization

[28] Little consideration has been given to the recent important work being done in Europe, a brief summary of which we find in Stahl und Eisen (1928), p. 961-971, by F. Toepfl.

experiments show that the gas absorption is much less than in the electric arc process and, probably, less than in the oxyacetlene welding.

3. In resistance welds of low carbon wire a very definite narrow strip of decarburized material along the weld is seen. Proof of the presence of oxide films which prevent grain growth is given in the fact that, although crystallization through the weld can take place, it does not always do so.

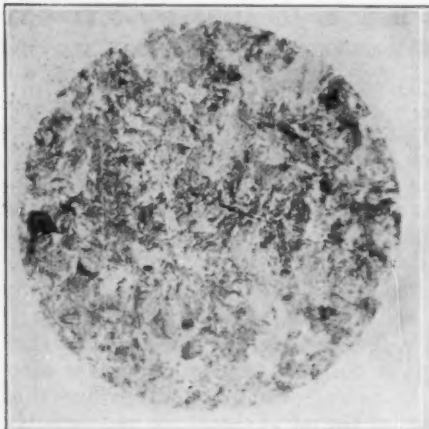


Figure 17 x200
The same as Fig.16 etched 3 sec. with alcoholic HNO_3.

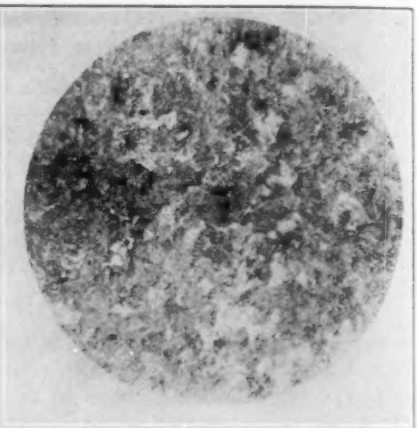


Figure 18 x200
Normal structure of the wire outside of the weld.

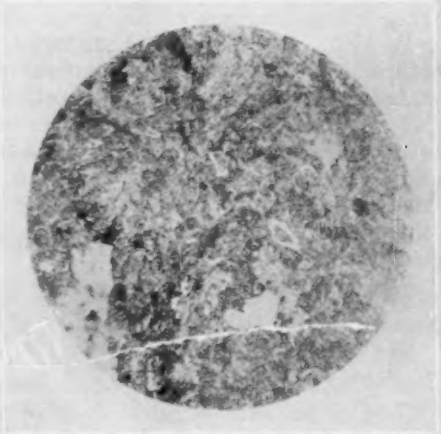


Figure 19 x200
Material outside of the weld after annealing 15 min. to 950°C. and slow cooling.

PHOTOMICROGRAPHS REDUCED TO ABOUT ½ ORIGINAL SIZE

CURRENT WELDING LITERATURE

Airplane Welding. J. B. Johnson. Published by Goodheart-Wilcox Co., Inc., 2009 Michigan Avenue, Chicago. Contains 320 printed pages. It is a practical handbook for mechanics and students, covering the following items: Methods of Joining Materials. The various methods of joining metals, including mechanical, soldering, brazing and welding methods. Oxy-Acetylene and Other Gas Welding. The fundamentals of gas welding—Description of equipment for gas welding—Torches—Regulators—Generators—Manipulation of torches—Tables for tip sizes—Methods of manufacturing jigs—Welding wire. Electric Welding. Latest types of equipment for electric welding of aircraft materials—Manipulation of the electrodes—Welding wire—Flash welding—Other pertinent data. Design of Welded Joints for Aircraft. Analysis of design of welded joints—Diagrams and figures showing a successful design—Examples of bad practice in the design of welded parts—Heat treatment of welds—Charts for the heat treatment of weldable steels used in aircraft construction. Aluminum Welding. Methods of aluminum welding—Design of aluminum gas tanks—Repair of aluminum castings. Inspection of Welds. Methods of inspecting welds—Strength preperties of welds. Repair of Welds. Repairing welded structures—Precautions to be used in making such repairs. Appendix. Containing complete information for the design of columns and struts. Tables for weight and area of tubes and tables for substitution of carbon for alloy tubes in repair work.

Arc Welded Steel Highway Bridge at Lowicz, Poland. (Le Pont-Route Metallique, Soude a l'Arc Electrique de Lowicz, Pologne.) S. Bryla. Genie Civil. (Sept. 14, 1929), Vol, 95, pp. 250-255. Design and construction of steel truss bridge 27 m. span; details of tests of welded parts; construction of reinforced concrete bridge floor.

Arc Welding. J. A. Hobbs. Mechanical and Welding Engineer (Sept. 20, 1929), Vol. 3, No. 9, pp. 310-314.

Arc Welding Thin Sheet Metal. J. B. Green. The Welding Engineer (October, 1929), Vol. 14, No. 10, pp. 56-57. New Carb-O-Flux process has been developed for the purpose of using the electric arc on thin sheets. What it is and what it does.

Autogenous Welding and Cutting. W. J. Wiggin. Railway Journal (September, 1929), Vol. 35, No. 9, pp. 30-31.

Automatic Thin-Sheet Arc Welding. W. L. Warner. The Iron Age (Sept. 26, 1929), Vol. 124, No. 13, pp. 834-837. Electro-Magnetic control necessary for good results. How the flux operates and how it is handled.

Building Erected by Gas Welding. Mechanical and Welding Engineer (Sept. 20, 1929), Vol. 3, No. 9, pp. 293-295. Use of Oxy-Acetylene method in factory structure. Valuable data secured for future work along same line.

Building Machinery by Electric Welding. Walter S. Rugg. Mechanical and Welding Engineer (Sept. 20, 1929), Vol. 3, No. 9, pp. 298-299.

Can Welding Jump the Hurdles? J. E. Tonnelier. Electrical World (Aug. 31, 1929), Vol. 94, No. 9, pp. 429-431. Electric welding of structures must reckon with difference in joint stress-distribution, with mill organization for fabrication of shapes, the designing engineer, the erection engineer and the riveter-welder.

Economy of Material in Welded Construction. The Welding Journal (October, 1929), Vol. 26, No. 313, pp. 315-316 and 331.

Electric Arc Welding. A. Ramsay Moon. Mechanical and Welding Engineer (Sept. 20, 1929), Vol. 3, No. 9, pp. 302-309.

Electric Welding of Field Joints of Oil and Gas Pipe Lines. H. C. Price. American Institute Mining and Metallurgical Engineers Technical Pub. No. 252, for meeting October, 1929, pp. 3-17.

First Arc-Welded Bridge in Europe, The. S. Bryla. Engineer (London) (Sept. 6, 1929), Vol. 148, pp. 248-249.

Fundamentals of Aluminum Welding. Acetylene Journal (November, 1929), Vol. 31, No. 5, pp. 207-209. Both the pure metal and its alloys can be successfully welded with the torch, but careful attention must be given to special procedure required for different classes of work.

Fusion-Welded Pressure Vessels. Engineer (London) (Sept. 13, 1929), Vol. 148, pp. 273-274.

Gas Welding Aluminum. W. A. Dunlap. The Welding Engineer (October, 1929), Vol. 14, No. 10, pp. 38-43. Welding properties of aluminum and its alloys. Importance of flux. Procedure for welding sheets and castings.

Good Preparation Insures Success. Acetylene Journal (November, 1929), Vol. 31, No. 5, pp. 213-214. Planning a cast iron welding job involves correct arrangements for preheating if hard spots and warping are to be avoided.

Government-Built Steel Motor Boats. John Van Horne. The Iron Age (Aug. 22, 1929), Vol. 124, No. 8, pp. 465-466. Fleet of ten built by United States Engineer Corps. Methods of shop fabrication outlined.

Installation for Aircraft Welding. J. F. Hardecker. Acetylene Journal (October, 1929), Vol. 31, No. 4, pp. 168-169. In arranging for production welding, consideration must be given to the practical factors as well as the theoretical.

Is the Boiler with Welded Seams Safe? Elec. Times (London) (Sept. 12, 1929), Vol. 76, pp. 369-371. Also, Elecn. (London) (Sept. 20, 1929), Vol. 103, pp. 325-326. Critical notes on welded points by boiler insurance expert; summary of conclusions is tabulated with sketch drawing.

Largest Gas Welded Structure Inspected by Engineers. Iron and Steel of Canada (Gardenvale, Que.) (September, 1929), Vol. 12, pp. 233 and 244. Methods used in gas welding of Union Carbide Company building at Niagara Falls are briefly discussed.

Mechanical Cutting in Redesign. Acetylene Journal (October, 1929), Vol. 31, No. 4, pp. 156-158. Mechanical oxy-acetylene cutting has added further economies in preparing the component parts of machinery made from fabricated rolled steel.

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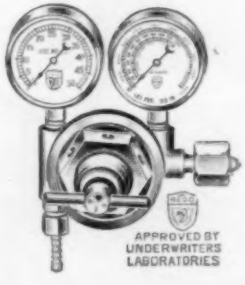

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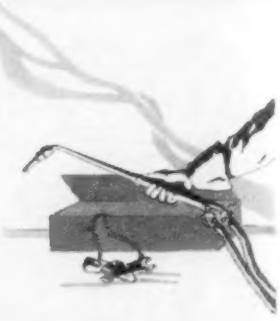

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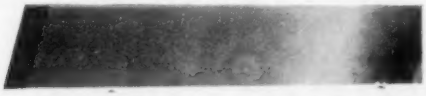

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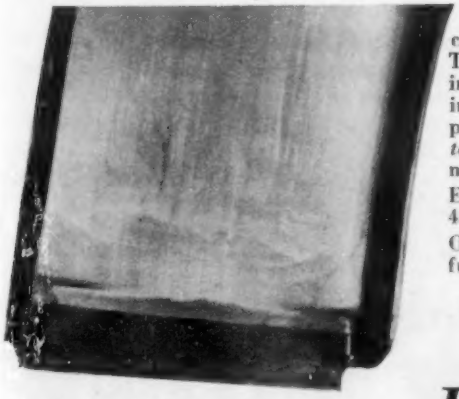

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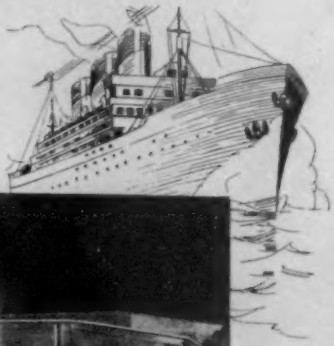

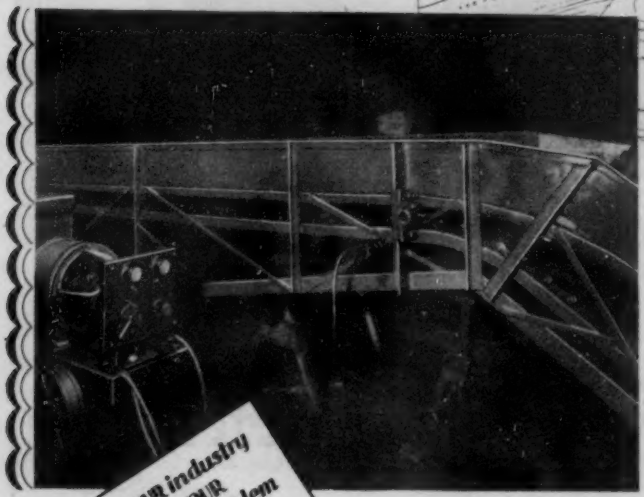

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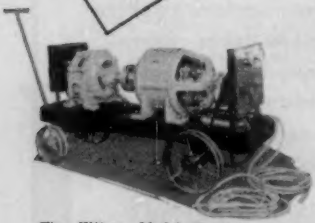

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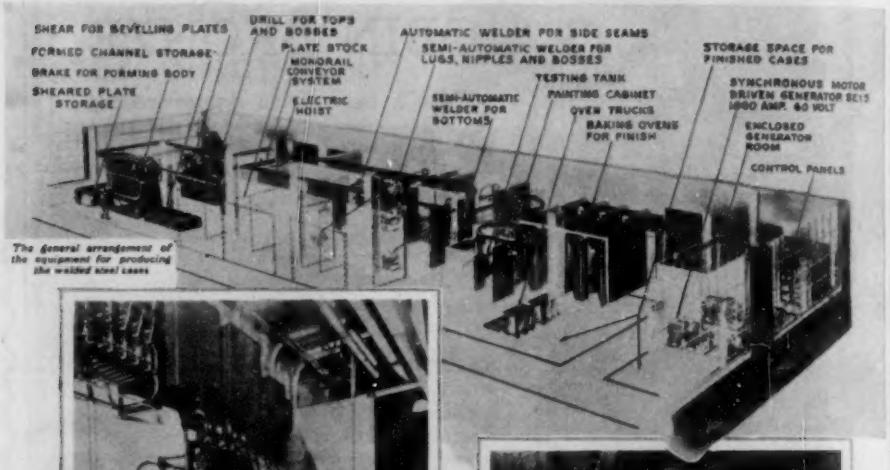
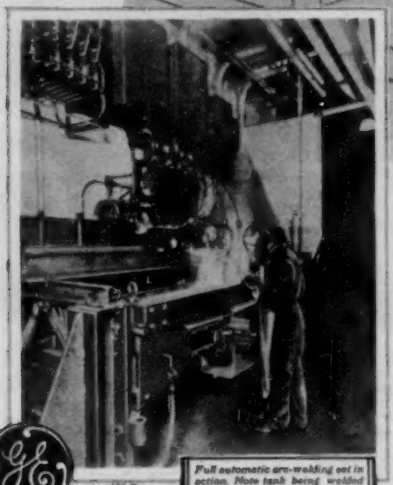


The general arrangement of the equipment for producing the welded steel cases



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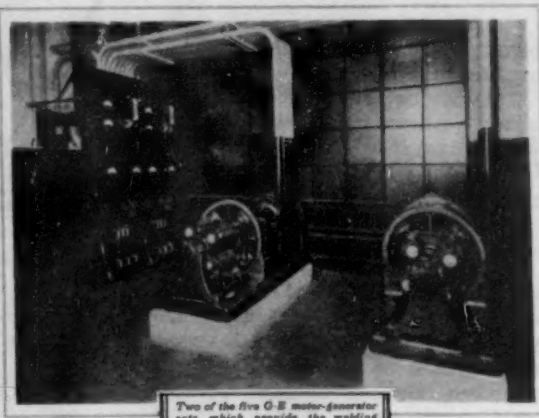

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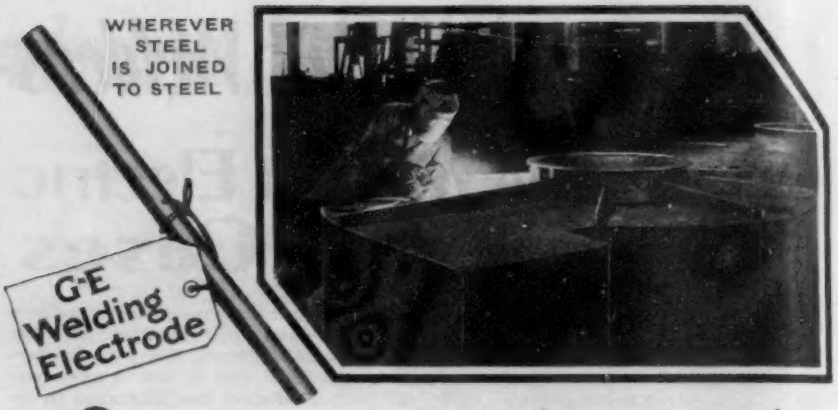

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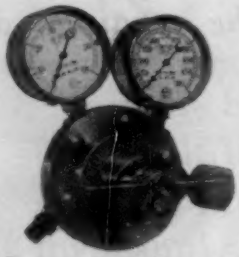

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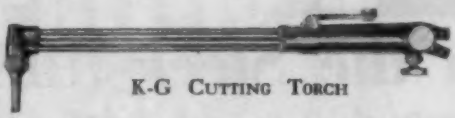

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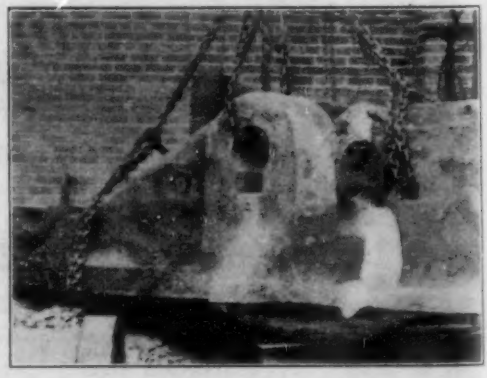

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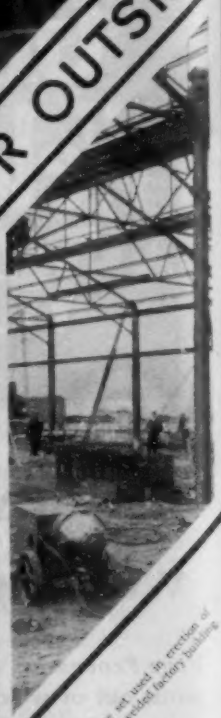

A 200-ampere set used in erection of an 815-ton arc welded factory building

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Greater welding speed is made possible with Westinghouse sets because the generator is separately excited, assuring instantaneous response to changing arc conditions. This gives an arc which is easy to strike and maintain. The welding current may be adjusted quickly and accurately by a single dial rheostat.

To stand the gaff of severe service, special attention has been given to the making of a machine which is compact, sturdy and weather-proof. The pictures illustrate the compactness of the set. Everything is there—welding generator, motor, control and reactor. These parts are built-in, fully protected, assuring dependable operation, outdoors, in all kinds of weather.

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"twenty-one voted the Airco-D. B. torch"

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An order was placed for twenty-six of these torches, completely standardizing our plant. This was on Feb. 28th, 1929, and since standardizing we have ordered fifteen more making us forty-one. Today we are ordering seven more making forty-eight.

Each welder is furnished with his own torch and is responsible for its care.

This letter was recently received from the H. C. Smith Company, a prominent California manufacturer.

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